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THESIS

MODELING BLUETOOTH RADIO TECHNOLOGY SIMULATON USING MULTI-AGENT BASED SYSTEM AND GENETIC ALGORITHM DESIGN PARADIGM

by

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March 2001

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The goal of the wireless world simulation is to explore the performance limitations and restrictions on the basis of the current Bluetooth™ technology specifications. This simulation will hopefully help Bluetooth™ system designers and decision-makers in gaining insight into the system performance analysis and enable them to make more informed decisions in the future.

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ABSTRACT

This thesis uses Multi-agent systems (MAS), and Genetic Algorithm (GA) techniques to develop a Bluetooth^{TM} radio system simulation that is called "*Wireless World*". Typically, wireless world is a simple two-dimensional (2D) toy model of Bluetooth^{TM} Technology implemented in the Java programming language version 1.2.1 and Borland jbuilder3 university edition editor environment. In addition, the wireless model is designed for outdoor environment for the six different weather conditions. And in the environment, there may be situated three types of interference systems. Within these systems, the IEEE 802.11b WLAN, an alternative to the BT, is implemented as interference in the simulation environment.

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LIST OF ABBREVIATIONS AND ACRONYM'S

ACK/NACK	Acknowledgement/ Negative Acknowledgement
ACL	Asynchronous Connectionless
AI	Artificial Intelligence
AP	Access Point
ARQ	Automatic Repeat Request Protocol
AU_RAND	128-Bit Random Number
BPSK	Binary Phase Shift Keying
BSS	Basic Service Set
BT	Bluetooth Technology
CAS	Complex Adaptive Systems
CCK	Complementary Code Keying
CDMA	Code-Division Multiple Access
CRC	Cyclic Redundancy Check
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
CSMA/CD	Carrier Sense Multiple Access with Collision Detection
CTS	Clear to Send
DAI	Distributed Artificial Intelligence
DCF	Distribution Coordination Function
DHCP	Dynamic Host Configuration Protocol
DGL	Demand Generator Layer
DS	Distribution System

DSSS	Direct Sequence Spread Spectrum
ESS	Extended Service Set
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission (USA)
FDMA	Frequency-Division Multiple Access
FEC	Forward Error Correction
FHSS	Frequency Hopping Spread Spectrum
FSK	Frequency Shift Keying
GA	Genetic Algorithm
GSM	Global System For Mobile Communication
HEC	Header Error-Check
HID	Human Interface Device
IBSS	Independent Basic Service Set
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IL	Infrastructure Layer
IP	Internet Protocol
ISA	Integrated Services Architecture
ISM	Industry, Scientific, and Medical
ISO	International Organization for Standardization
KQML	Knowledge Query and Manipulation Language
LAN	Local Area Network
L2CAP	The Logical Link Control And Adaptation Protocol

LLC	Logical Link Control
LM	The Link Manager
MAS	Multi-Agent System
MAC	Media Access Control
MIB	Management Information Base
MKK	Radio Equipment Inspection and Certification Institute (Japan)
MOVES	Modeling, Virtual Environments and Simulation
NIC	Wireless Network Interface Card
NOS	Network Operating System
NPS	Naval Postgraduate School
PDAs	Personal Digital Assistants
PAM	Polled Access Mode
PCF	Point Coordination Function
PCI	Peripheral Component Interconnect
PRNG	Pseudo Random Number Generator
QPSK	Quadrature Phase Shift Keying
RC4	Ron's Code or Rivest's Cipher
RFCOM	Radio Frequency Communication
RTS	Request to Send
RX	Reception
SCO	Synchronous Connection-Oriented
SDP	Service Discovery Protocol
SIG	Bluetooth Special Interest Group

SNMP	Simple Network Management Protocol
SRES	32-Bit Signed Response
TCP/IP	Transmission Control Protocol/Internet Protocol
TCS	Telephone Control Specification
TDD	Time-Division Duplex
TX	Transmission
VE	Virtual Environment
VCO	Voltage Controlled Oscillators
WAP	The Wireless Application Protocol
WECA	Wireless Ethernet Compatibility Alliance
WEP	Wired Equivalent Privacy
WLAN	Wireless Local Area Network
WLANA	Wireless LAN Alliance

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I. INTRODUCTION

A. MOTIVATION

Over the recent years, wireless radio technologies have amazingly grown, and the wireless technologies now reach or are capable of reaching virtually everywhere on the face of the earth. Hundreds of millions of people exchange information every day using pagers, cellular phones, palm pilots, laptops, and other wireless communication devices. So, the power of wireless networking and collaborative, distributed computing are inevitably important.

Among the wireless technologies, two competing wireless radio systems, Bluetooth (BT), and 802.11b WLAN, have a leading role in the arena. Both technologies are almost new and are still under development. The major motivations and benefits of these wireless technologies are increased mobility, lower installation time and simplicity, scalability, flexibility, and economical to use. But even though there is no comprehensive computer simulation of the BT or 802.11b WLAN, modeling of these two systems are very complex, and hard to simulate in the computer environment.

On the other hand, recent research in the field of distributed artificial intelligence (DAI), multi-agent systems (MAS), and complex systems theory has demonstrated that ill-defined problems and complex systems can be effectively modeled using agent-based simulation techniques [Ref. 4]. In addition, the main concerns on MAS: 1) simplifying

the complexities of distributed computing system, and 2) overcoming the limitations of current user interface approaches.

Therefore, today's modeling and simulation (M&S) communities are being challenged by ever-increasing demands to create rich, detailed models of ill-defined problems. Most of these problems are complex because of the involvement of human decision-making and organizational behavior. Humans and organizations have multiple levels of internal roles, goals and responsibilities, frequently conflicting with each other.

B. OBJECTIVE

Four main objectives were taken up by this thesis, as summarized below:

- Review MAS and Genetic Algorithms (GA) systems;
- Introduce and compare Bluetooth and 802.11b WLAN radio technologies;
- Design and implement MAS simulation of the Bluetooth wireless system in the java-based computer language by using GA; and,
- Analyze the potential benefits and performance of the system that will be obtained.

This toy model is called "Wireless World". The main goal of developing the Wireless World simulation is to explore the limitations and restrictions of the BT wireless radio system in different conditions and situations.

C. ORGANIZATION OF THESIS

This thesis is organized into the following Chapters:

- Chapter I: Introduction. This Chapter gives an overview of the problem, motivation, objective, and general outline of the thesis. In addition, it provides information about the background, and objective of the study.
- Chapter II: Background. This Chapter provides background information required to understand the thesis. I review some issues, related to Multi Agent Simulation (MAS) and the Wireless World toy model. Hence, information will be presented as a general introduction to MAS.
- Chapter III: Genetic Algorithm. This Chapter reviews and presents background information about the GA basics according to the design aspect, and describes some GA key concepts and terms.
- Chapter IV: Bluetooth Radio System. This Chapter reviews BT wireless radio technology, and presents background information about BT system architecture, and describes some key concepts and terms.
- Chapter V: IEEE 802.11b WLAN Technology. This Chapter first provides a general description of the IEEE 802.11b WLAN and briefly explains the architecture of the system.
- Chapter VI: Bluetooth versus IEEE 802.11b WLAN. This Chapter presents the comparison of BT and IEEE 802.11b WLAN wireless radio technologies, and determines pros and cons of both systems.

- Chapter VII: Wireless World Design Paradigm and Architecture. This Chapter takes the reader through the Wireless World application program design. It explains how the model infrastructure and architecture those are implemented in the Java programming language and provides information about the Java classes implemented in the application program.
- Chapter VIII: Conclusions. This Chapter provides a short summary of the thesis and addresses possible future enhancements that might be made to the current developed system.

II. BACKGROUND

"The idea of an agent originated with John McCarthy in the mid-1950's, and the term was coined by Oliver G. Selfridge a few years later, when they were both at the Massachusetts Institute of Technology. They had in view a system that, when given a goal, could carry out the details of the appropriate computer operations and could ask for and receive advice, offered in human terms, when it was stuck. An agent would be a 'soft robot' living and doing its business within the computer's world" [Ref. 17].

A. INTRODUCTION

In this thesis, Multi-Agent Systems (MAS) are used to model a simulation of Bluetooth Wireless Radio Technology. Therefore, this Chapter provides background information required to understand the MAS, and related subject, terms, and definitions. Hence, information will be presented about general introduction of MAS, explaining the key concepts and definitions, advantages of MAS, and some examples of MAS and Distributed Artificial Intelligence (DAI) applications. Since most of the computer science communities accept, DAI and MAS have similar meaning. Then, in my thesis, I used these two terms in the same meaning, and mostly DAI includes the MAS.

Over the last decade, multi-agent systems (MAS) have become more and more important in many aspects of computer science (e.g., artificial intelligence, distributed systems, robotics, etc.) by introducing the issue of collective and cooperative intelligence and of the emergence of structures through interactions. MAS focus on the autonomy of individuals, called "agents".

The first important area is the theoretical and experimental analysis of the self-organization mechanisms that come into play when several autonomous entities interact. The second is the creation of distrusted artifacts capable of accomplishing complex tasks through cooperation and interaction [Ref. 5]. Above all, the long-term goal of MAS and DAI is to develop mechanisms and methods that enable agents to interact, to be capable of performing complex tasks as well as humans (or even better), and to understand interaction among intelligent entities whether they are computational, human, or both.

Today, there are lots of MAS computer applications in different areas, such as biology, social sciences, business, military, etc. Understanding of the key concepts on MAS is an important issue in order to build an agent-based model. Unfortunately, many of the commonly used terms in the fields of (Distributed Artificial Intelligence) DAI and MAS research do not have commonly agreed upon definitions by the research communities [Ref. 30].

B. KEY CONCEPTS, DEFINITIONS, AND TERMS

This part of the Chapter highlights several key definitions and concepts as they are used in this thesis. Many of these terms are hardly defined in the research community, but a common understanding, is important, nonetheless. Unfortunately, many

of the commonly used terms and definitions in the fields of DAI and MAS research do not have commonly agreed upon definitions by the research communities.

1. Agent

The *American Heritage Dictionary* defines an agent as "one that acts or has the power or authority to act… or represent another" or the "means by which something is done or caused; instrument." The term derives from the present participle of the Latin verb *agere:* to drive, lead, act, or do. As in the everyday sense, we expect a software agent to act on behalf of someone to carry out a particular task, which has been delegated to it.

In [Ref. 14], a comprehensive definition of agents is given that "agents are autonomous, computational entities that can be viewed as perceiving their environment through sensors and acting upon their environment through effectors. The environments can be accessible vs. inaccessible, deterministic vs. non-deterministic, episodic vs. non-episodic, static vs. dynamic, and discrete vs. continuous. "*Computational entities*" simply means that they physically exist in the form of programs that run on computing devices. "*Autonomous*" means that to some extent agents have control over their behavior and can act partially depends on its own experience without the intervention of humans and other systems at least. Agents pursue goals or carry out tasks in order to meet their design objectives, and in general these goals and tasks can supplementary as well as conflicting."

According to the definitions above, "***agents***" have a number of properties: (1) Action—able to modify their environment; (2) Communication—signals or messages; (3)

Intentions—intrinsic to autonomy; (4) Resources—where withal to do things; (5) Partial Knowledge—point of view; (6) Capability—skills, services; and (7) Feedback—persistence, reproduction [Ref. 2].

In the application arena, an agent can be a software object, a robot, a living being, or anything that fulfills the basic concepts of agency. In the context of this thesis, the use of the word *agent* will always imply *software agent* as opposed to any other kind, unless specifically stated.

2. Intelligent

"***Intelligent***" indicates that the agents pursue their goals and execute their tasks such that they optimize some given performance measures. Agents are intelligent does not mean that they are all knowing or omnipotent, nor does it mean that they never fail. Rather, it means that they operate flexibly and rationally in a variety of environmental circumstances, given the information they have and their perceptual and effectual capabilities. A major focus of DAI therefore is on processes such as problem solving, search, planning, decision-making, and learning that make it possible for agents to show flexibility and rationality in their behavior, and on the behavior of such processes in MAS scenarios [Ref. 14].

3. Interaction

"***Interaction***" indicates that the agents can be affected by other agents or perhaps by humans in following their goals and executing their tasks. Interaction can take place indirectly through the environment in which they are embedded (e.g., by observing one another or by carrying out an action that modifies the environmental state) or directly

through a shared language (e.g., by providing information in which other agents are interested or which confuses other agents) [Ref. 14].

There are different types of interaction (e.g., coordination, mating, combat, communication, trade, rivalry, attraction, or partnership, etc.) among the agents, or between an agent and an object. Key one is "*coordination*" as a form of interaction that is particularly important with respect to goal attainment and task completion. To coordinate their goal and tasks, agents have to explicitly take dependencies among their activities into consideration. Besides, two basic contrasting pattern of coordination are "*cooperation*" and "*competition*". In the case of cooperation, several agents work together and draw on the broad collection of knowledge and capabilities to achieve a common goal. Cooperating agents try to accomplish as a team what the individuals cannot, and so fail or succeed together. Contrarily, in the case of competition, a number of agents work against each other because their goal conflicting. *Competitive* agents try to maximize their own benefit ad the expense of others, and so the success of one implies the failure of others.

4. Adaptation

In the context of agents, mostly, adaptation and learning are used together, and one completes another. Learning and adaptation are closely related, with learning actually being a means to adaptation [Ref. 30]. If an agent uses feedback to modify its own decision-making process, it is no longer simply reacting to its environment, it is also adapting to form a better fit to its environment. When one talks about adaptation of a

species, the time scale is now much longer, spanning multiple generations, and is usually considered *evolution*.

Adaptation encompasses both evolution, on a population or macro scale, and learning, on an individual or micro scale. When an individual organism adapts to its environment, it is generally considered learning. When a species adapts to its environment, it is considered evolutionary change. Adaptation implies a modification according to changing circumstances. Modification of an organism or its parts make this organism more fit for existence under the conditions of its environment.

Adaptation, in the biological usage, is the process whereby an organism fits itself on its environment. Roughly, experience guides changes in the organism's structure so that as time passes the organism makes better use of its environment for its own ends. Therefore, the adaptation term includes learning [Ref. 3].

5. Complex Adaptive Systems (CAS)

The behavior of the "***CAS***" is more than a simple sum of the behaviors of its parts; CAS abounds in nonlinearties. And, adaptation gives rise to a kind of complexity that greatly hinders the people's attempts to solve some of the most important problems (such as inner-city decay, AIDS, mental disease, trade balances, birth defects, and computer viruses, etc.) currently posed by our world.

Many other complex systems show coherence in the face of change. For instance, the coherence and persistence of each system depend on extensive interactions, the aggregation of diverse elements, and adaptation or learning [Ref.3].

In [Ref. 3], Holland defines the seven basic elements of CAS:

a. Aggregation

*"**Aggregation**"* enters into the study of CAS in two senses. The first refers to standard way of simplifying complex systems. All similar things are aggregated into categories—trees, cars, and banks– and then treat them as equivalent. In addition, the categories that are chosen are reusable. So, aggregation is one of the basic techniques for constructing model.

The second sense of aggregation is closely related to the first one, but it is more a matter of *what CAS does*, rather than *how* we model the system. Typically, this concerns the emergence of complex large-scale behaviors from the aggregate interactions of less complex agents. For example, the individual ant has a higly-stereotyped behavior, and it almost always dies when its circumstances do not fit the stereotype. On the other hand, the ant aggregate —the ant nest—is highly adaptive, surviving over long periods of time in the face of a wide range of dangers.

b. Tagging

*"**Tagging**"* is a mechanism than consistently facilitates the formation of aggregates. The visual patterns and pheromones facilitate selective mating in animals, and the trademarks, logos, and icons that facilitates commercial interactions. And CAS use tags to manipulate symmetries. Because the symmetries are common, we often use this symmetries in perceiving or modeling our daily life, and sometimes quite unconsciously. In addition, these symmetries enable us to ignore certain details, while directing our attention to others. The most familiar example is a banner or flag that is used to rally members of an army or people of similar political parties.

c. *Nonlinearity*

In general, most of the mathematical laws or tools rely on the assumption of linearity. Roughly, linearity means that we can get a value for the whole by adding up the values of its parts. In contrast to the classical systems, CAS have nonlinear interactions. Because the nonlinear interactions almost always make the behavior of the aggregate more complicated than would be predicted by summing or averaging.

d. *Flow*

"***Flows***" is like over a network of nodes and connectors. The nodes may be factories, and the connectors may be transport routes for the flow of goods between the factories. Similar {node, connector, and resource} triads exist for other CAS: {nerve cells, nerve cell interconnections, and pulses} for the central nervous system; {computer stations, cables, and messages} for the electronic Internet; and so on. In general terms, the nodes are processors—agents—and the connectors designate the possible interactions.

e. *Diversity*

"***Diversity***" is neither accidental nor random. The persistence of any individual agents, whether organism, neuron, or firm, depends on the context provides of the other agents. Roughly, each kind of agent fills a niche that is defined by the interactions centering on that agent. If any kind of agent is removed or dies in the system, creating a "hole", the system typically responds with a cascade of adaptations resulting in a new agent that "fills the hole". The new agent typically occupies the same niche as the deleted agent and provides most of the missing interactions. So each new adaptation opens the possibility for further interactions and new niches.

f. Internal Models

In the "***Internal Models***", the models of interest here are interior to the agent, the agent must select pattern in the torrent of input it receive and then must convert those patterns into changes in its internal structures. The changes in structure, the model, must enable the agent to *anticipate* the consequences that follow when that pattern is again encountered. The models do depend more directly on the agents' sensory experience. At the same time, the agents' environment actively determines the agents' behavior.

In order to clearly understand the internal model concept, it is beneficial to define two internal models: *tacit* and *overt.* A tacit internal model simply defines a current action, under an implicit prediction of some desired future states, as in the case of the bacterium. An overt internal mode is used as a basis of explicit, but internal, explorations of alternatives, a process often called *look-ahead.* The distinctive example of look-ahead is the mental exploration of possible move sequences in chess prior to moving a piece.

g. Building Blocks

"***Building blocks***" serve to impose regularity on a complex world. In real situations, an internal model must be based on limited sample of a perpetually novel environment. Yet the model can only be useful if there is some kind of repetition of the situations model. Because we gain experience through repeated use of the building blocks, even though they may never twice appear in exactly the same combination.

For instance, we may consider as the common building blocks of a human face: hair, forehead, eyebrows, eyes, and so on. Let's decompose the face into ten

components (one of which is "eyes"), and allow ten alternatives for each component (as in "blue eye", "brown eye", "hazel eye," etc.). We can think of ten "bags" holding ten building blocks each, for a total of 10 x 10 matrix with total of 100 different building blocks. Then we can construct a face by choosing one building block from each bag.

6. Mobile Software Agents

"***Mobile Software Agents***" are software components that are able to migrate among different locations of a network, such as intranet or the Internet, in order to perform their tasks. Since the mobile agents maintain an internal execution state and/or data state, they are able to perform different parts of their task sequentially on different network locations. By moving from one network server to another, and communicating locally with the servers, mobile agents can reduce the need for network availability to the short time of their migration [Ref.34].

Mobile agents enable the dynamic and automated installation, maintenance, and reconfiguration of software components on any end devices and network nodes. By enabling an administrator to control these activities at a single location (instead of traveling around as usually required in case current systems) or even to delegates these activities to the respective mobile agents, so a considerable amount of time and money can be saved.

7. Distributed Artificial Intelligence (DAI)

"DAI" is the study, construction and application of multi-agent systems (MAS), that is, systems in which several interacting, intelligent agents pursue some set of goal, or

perform some set of tasks. DAI primarily focuses on coordination as a form of interaction that is particularly important with respect to goal attainment and task completion. The purpose of coordination is to achieve or avoid states of affairs that are considered as desirable or undesirable by one or several agents. [Ref.14].

What are the basic concerns with DAI? The first is that MAS have the capacity to play a key role in current and future computer science and applications. Modern computing platforms and information environments are distributed, large, open, and heterogeneous. The increasing complexity of computers and information systems goes together with an increasing complexity of applications. To cope with such applications computer act more as "individuals" or agents, rather than just "parts" or "objects". At this point, the technologies that DAI promises to provide are among those that are urgently needed for managing high-level interaction in and intricate applications for modern computing and information processing systems.

The second reason is that MAS have the capacity to play an important role in developing and analyzing models and theories on interactivity in human societies. Human interacts in various ways and at many levels: for instance, they observe and model one another, they request and provide information, they negotiate and discuss, they develop shared views of their environment, they detect and resolve conflicts, they form and dissolve organizational structures such as teams, committees, and economies. Many interactive processes among humans are still poorly understood, although they are an integrated part of our everyday life. DAI technologies enable us to explore their sociological and psychological foundations.

8. MAS

Typically, ***"MAS"*** can differ in the agents themselves, the interactions among the agents, and the environments in which the agents act. A key pattern of interaction in MAS is goal- and task-oriented coordination, both in cooperative several agents try to combine their efforts to accomplish as a group what the individuals can not, and in the case of competition several agents try to get what only some of them can have.

Therefore, MAS are composed of seven basic elements: (1) Environment—that the agents may act and the objects may be situated; (2) Objects—a set of object; (3) Agents—a set of agents having intelligence and intrinsic behaviors; (4) Relationship—interaction among agents, or between agents and objects; (5) Operation—a set of operations by agents on objects; and (6) Laws—a set of rules that the agents have to obey during the certain operations.

On the other hand, MAS are based on Agent-based modeling that is a third way of doing science (e.g., deduction and induction). Like deduction, it starts with a set of explicit assumptions. But unlike deduction, it does not prove theorems. Instead, an agent-based model generates simulated data that can be analyzed inductively. Unlike typical induction, however, the simulated data come from a rigorously specified set of rules rather than direct measurement of the real world. Whereas the purpose of induction is to find patterns in data and that of deduction is to find consequences of assumptions, the purpose of agent-based modeling is to aid intuition [Ref. 1].

Agent-based modeling is a way of doing thought experiments. Although the assumptions may be simple, the consequences may not be at all obvious. Numerous examples appear throughout this volume of locally interacting agents producing large-

scale effects. The large-scale effects of locally interacting agents are called "emergent properties" of the system. Emergent properties are often surprising because it can be hard to anticipate the full consequences of even simple forms of interaction.

The main alternative to the assumption of rational choice is some form of adaptive behavior. The adaptation may be at the individual level through learning, or may be at the population level through differential survival and reproduction of the more successful individuals. Either way, the consequences of adaptive process are often very hard to deduce when there are many interacting agents following rules that have nonlinear effects. Thus the simulation of an agent-based model is often the only viable way to study populations of agents who are adaptive rather than fully rational.

In [Ref. 14], for building MAS in which the agents "do what they should do" turns out to be particularly difficult and challenging in the light of the basic system characteristics. However, if we would like to build MAS, we should solve most of the following challenging issues:

1. How to enable agents to decompose their goals and tasks, to allocate sub-goals and sub-tasks to other agents, and to synthesize partial results and solutions.
2. How to enable agents to communicate. What communication languages and protocols to use.
3. How to enable agents to represent and reason about the actions, plans, and knowledge of other agents in order to appropriately interact with them.
4. How to enable agents to represent and reason about the state of their interaction processes. How to enable them to find out whether they have

achieved progress in their coordination efforts, and How to enable them to improve the state of their coordination and to act coherently.

5. How to enable agents to recognize and reconcile disparate viewpoints and conflicts. How to syntheses views and results.

6. How to engineer and constrain practical MAS. How to design technology platforms and development methodologies for DAI.

7. How to effectively balance local computation and communication.

8. How to avoid or mitigate harmful (e.g., chaotic or oscillatory) overall systems behavior.

9. How to enable agents to negotiate and contract. What negotiation and contract protocols should they use?

10. How to enable agents to form or dissolve organizational structures –teams, alliances and so on- that are suited for attaining their goals and completing their tasks.

11. How to formally describe MAS and the interactions among agents. How to make sure they are correctly specified.

12. How to realize "intelligent process" such as problem solving, planning, decision-making, and learning in multi-agent contexts. How to enable agents to collectively carry out such processes in a coherent way.

C. ADVANTANGES OF MAS

1. Speed-up and Efficiency

In MAS, agents can operate asynchronously an in parallel, and this can result in an increase overall speed (provided that the overhead of necessary coordination does not outweigh this gain).

2. Robustness and Reliability

The failure of one or several agents does not necessarily make the overall system useless, because other agents already available in the system make take over their part.

3. Scalability and Flexibility

The system can be adapted to an increased problem size by adding new agents, and this does not necessarily affect the being operational of the other agents.

4. Cost

MAS may be much more cost effective than a centralized system, since it could be composed of simple subsystems of low unit cost.

5. Development and Reusability

Each individual agent can be separately developed by the specialists (either from scratch or on basis of already available hardware and/or software facilities). The overall

system can be tested and maintained more easily, and it may be possible to reconfigure and reuse agents in different application scenarios.

6. Natural View of Intelligent Systems

MAS offer a natural way to view and characterize intelligent system. In natural systems, intelligent beings organize themselves into various group, committees, societies, and economies in order to achieve improvement. Intelligence and interaction are inevitably coupled, and MAS reflect this insight. Natural intelligent systems, like human, do not function in isolation. Instead, they are at least a part of the environment in which they and other intelligent systems operate. For instance, Humans can interact in various ways and at various levels, and most what humans have achieved is a result of interaction.

7. Technological and Application Needs

MAS offer a promising an innovative way to understand, mange, and use distributed, large-scale, dynamic, open, and heterogeneous computing and information systems. Internet is the most prominent example of such systems; other examples are multi-database systems and in-house information systems. Computers and computer software applications play an increasingly important and influencing role in our daily life. These systems are too complex to be completely characterized and precisely described. As computer systems' control becomes more and more decentralized, their components act more and more like "individuals" that deserve attributes like autonomous, rational, intelligent, and so on rather than just as "parts". Not only MAS and DAI aim at

providing know-how for building sophisticated interactive systems form scratch, but also for interconnecting existing legacy systems such that they coherently act as a whole.

D. MAS AND DAI APPLICATIONS

In [Ref.14] and [Ref. 5], most existing and potential industrial and commercial applications for DAI and MAS are described. I list some of these applications below:

- Electronic commerce and electronic markets, where "buyer" and "seller" agents purchase and sell goods on behalf of their users. These agents shares six similar basic stages of buying process: (1) Need identification, (2) Product brokering, (3) Merchant brokering, (4) Negotiation, (5) Purchase and delivery, (6) Product services and evaluation [Ref. 33]
- Real time monitoring an management of telecommunication networks, where agents are responsible, e.g., for call forwarding, and signal switching and transmission.
- Modeling and optimization of in-house, in-town, national- or world-wide transportation systems, where agents represents, e.g., the transportation vehicles or the goods or customers to be transported.
- Information handling in information environments like the Internet, where multiple agents are responsible, e.g., for information filtering and gathering.
- Improving the flow of urban or air traffic, where agents are responsible for appropriately interpreting data arising at different sensor stations.

- Automated meeting scheduling, where agents act on behalf of their users to fix meeting details like location, time, and agenda.
- Optimization of industrial manufacturing and production process like shop floor scheduling or supply chain management, where agents represents, e.g., different work-cells or whole enterprise.
- Electronic entertainment and interactive, virtual reality-based computer games, where, e.g., animated agents equipped with different characters play against each other or against human users.
- Design and reengineering of information and control flow patterns in large-scale natural, technical, and hybrid organizations, where agents represent the entities responsible for these patterns.
- Simulation of some biological animals, that are living and moving in large groups, such as flock of bird, ant colonies, swarm of bees, etc. in their natural environment, where agents represent the entities responsible for individual animals.
- Investigation of social aspects of intelligence and simulation of complex social phenomena such as the evolution of roles, norms, and organizational structures, where agents take on the role of members of the natural societies under consideration.

III. BASICS OF GENETIC ALGORITHMS

A. INTRODUCTION

Designers of artificial systems, or business systems –both software and hardware, can only marvel at the robustness, efficiency, and the flexibility of biological systems. The features of the basic rule in biological systems are self-repair, self-guidance, adaptive, and reproduction.

Genetic algorithms (GA) are search algorithms based on the mechanics of natural selection theory and natural genetics. Also GA have been introduced as an efficient optimization technique. GA imitates biological evolution (gene theory) with recombination, as in sexual reproduction in addition to mutation as sources of the random variation. In [Ref. 3], GA's main goal is a study the phenomenon of adaptation as it occurs in nature and to develop ways in which the mechanisms of natural adaptation might be imported into computer systems. In this context, GA provides a strong alternative to simple random variation and selection models.

As stated in [Ref. 6], GA are different from the normal optimization and search procedures in four ways:

1. GA work with a coding of the parameter set (direct manipulation of coding), not the parameters themselves.
2. GA search from population of points, not a single point.
3. GA use a fitness (objective) function (search via sampling), not derivative or other auxiliary knowledge.

4. GA use probabilistic transition rules, not deterministic rules.

First, in many optimization methods, they move from a single point in the decision space to the next using some transition rule to determine the next point. This point-to-point method is dangerous because it is an effective prescription for locating false peaks in many-peaked search space. In contrast, GA work from a rich database of points simultaneously (population of strings), climbing many picks in parallel; thus the probability of finding a false peak is reduced over methods that go point-to-point. GA starts with a population of strings and thereafter generates successive population of strings.

Second, GA has no need to for auxiliary information; GA are blind. To perform an effective search for better and better structures, the system only needs objective function values associated with individual strings. In nature, fitness (the number of offspring that survive to reproduction) is ultimate and the only goal. Large numbers of offspring survive because they are fit. GA uses random choice as a tool guiding a search toward regions of search space.

Finally, the transition rules of GA are stochastic; many other methods have deterministic transition rules. A distinction exists, however, between the randomized operators of GA and other methods that are simple walks. GA uses choice to guide a highly exploitative search.

B. COMPARISON OF NATURAL SYSTEMS AND GA

GA are originated in natural genetic theory. The strings of artificial genetic systems are analogous to *chromosomes* in biological systems. A chromosome can be

conceptually divided into *genes* –functional block of DNA. In natural systems (illustrated in Figure 3.1), one or more chromosomes combine to form the total genetic prescription for construction an operation of some organisms.

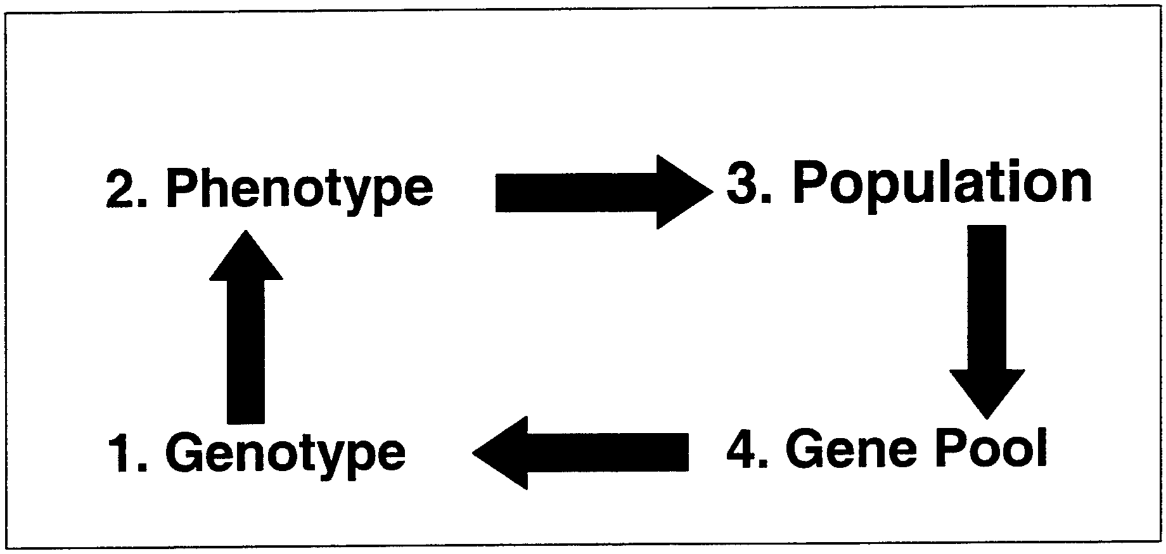

Figure 3.1. Nature's Algorithm

In natural systems, the total genetic package or a particular set of genes in the complete collection of genetic material is called the *genotype* –expression and development of the system. In artificial genetic systems, the total package of strings is called a *structure*. In natural systems, the organism formed by interaction of the total genetic package with its environment is called the *phenotype* –systems physical and mental characteristics, such as in the human, eye color, height, brain size, intelligence etc. In artificial genetic systems, the structures decoded to form a particular *parameter set*, *solution alternative*, or *point* in the solution space. In natural terminology, chromosomes are composed of *genes,* which may take on some number of values called *alleles*. All of the genes of a species make up that species' *gene pool,* which, in turn, supports both the continuation and modification of that species. In genetics, the position of a gene, which

is called *locus*, is identified separately from the gene's function. In artificial genetic systems, strings are composed of *features* of *detectors*, which take on different values. Features may be located at different *positions* on the string.

C. SIMPLE GENETIC ALGORITHM

Typically, a simple GA has at least the following elements in common: population of chromosomes, selection according to a fitness (objective) function (reproduction), crossover to produce new offspring, and a random mutation of new offspring.

1. Reproduction

Reproduction is a process in which individual strings are copied according to their objective (fitness) function values. For instance, the fitness of an organism is typically defined as the probability that the organism will live to reproduce or as a function of the number of offspring the organisms has (fertility). In the artificial version of natural selection, copying strings according to their fitness function values means that the more effective strings have a higher probability of contributing one or more offspring in the next generation. In natural populations, fitness is determined by a creature's ability to survive predators, pestilence, and the other obstacles to adulthood and subsequent reproduction [Ref. 6]. More highly fit strings have a higher number of offspring in the succeeding generation. Once a string has been selected for reproduction, an exact replica of the string is made. This string and the others it is combined with at reproduction will eventually express a new phenotype (i.e., a new individual), which will have an

opportunity to survive and perhaps enter some future mating pool of adults; having effectively coped with the pressures of selection, the string in question may carry forward into future generations.

2. Crossover

After the reproduction phase, simple ***crossover*** is composed of two steps. First, strings (i.e., genes) of chromosomes that have entered the gene pool are randomly selected for mating. Note that these chromosomes survived the non-random pressure of selection in order to enter this gene pool. Second, each pair of strings undergoes crossing over as follows: an integer position $\boldsymbol{k}$ along the string is selected uniformly at random between 1 and the string length minus one $[1, \boldsymbol{l}-1)$. Swapping all the characters between position $k+1$ and l inclusively creates two new strings.

3. Mutation

Mutation plays a decidedly secondary role in the operation of genetic algorithms, compared to crossover. Mutation is needed because even though reproduction and crossover effectively search and recombine existing notions, on the other hand, occasionally in the first two steps, it may be lost some potentially useful genetic material at particular gene locations. In artificial genetic systems, the mutation operator system protects against such an irrecoverable loss. It can also lead to new strings that never were in the gene pool of the species.

By itself, mutation is a random walk through the string space. When mutation is used sparingly with reproduction and crossover, it is an insurance policy against

premature loss of important information. Typically, mutation rates are similarly small in natural populations. Therefore, in a simple GA system, researchers generally use on the order of one mutation per thousand bit (position) transfers (the probability of 0.001), or less.

D. SUMMARY

This Chapter typically highlights some key definitions and concepts about GA as they are used in this thesis. In technology and science GA have been used as adaptive algorithms for solving practical problems such as, optimization problems, machine learning, economics, social systems, etc., and as computational models of natural evolution systems.

In my wireless world application program, I used GA for exploring the limitations and restrictions of BT system performance in different experimental settings on the demand layer of implementation. Basically, GA provide to search from population of points, not a single point, and a new adapted behaviors back to the MAS. Due to the fitness function, GA results the best solutions for its mating pool.

IV. THE BLUETOOTH RADIO TECHNOLOGY

A. INTRODUCTION

The Bluetooth Technology (henceforth, BT), a new universal radio interface, is a code-name for a wireless technology specification, and truly low-cost (today, BT-chip costs roughly $45), short-range (the nominal link range is 10 centimeters to 10 meters, but can be extended to more than 100 meters by increasing the transmit power), and small-sized (i.e., a 9 x 9 mm microchip) data or voice radio links among PCs, laptops, notebooks, cordless phones, cellular phones, modems, printers, desktops, fax machines, keyboards, joysticks, headsets, digital cameras, personal digital assistants (PDAs), their peripherals and other portable devices. Eventually, these embedded radios will lead toward ubiquitous connectivity and, for communication devices, connect everything to everything [Ref. 25].

BT technology is operating system independent. Today, implementations of the BT specification for several commercial operating systems are under development.

BT has gained the support of today's leading companies such as Ericsson, Nokia, IBM, Microsoft, Toshiba, and Intel. In 1999, these companies formed the Bluetooth Special Interest Group (SIG). Today, more than 2000 organizations have joined the SIG, and most of them are currently developing BT-enabled products under a specification developed by the group.

In the real world, BT can be used for a variety of purposes, and will potentially replace multiple cable connections via a single radio link. BT-enabled products will

automatically seek each other out and configure themselves into networks. Though small, such networks can be quite useful.

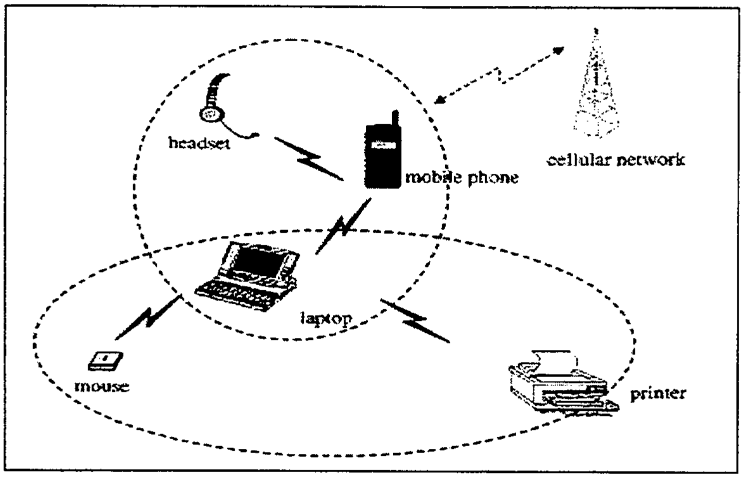

Figure 4.1. BT applications envisioned for the near future [From: Ref. 36].

The first BT products will emerge in mid-2000 and focus on mobile applications (mobile phones, notebook computers, and accessories; see Figure 4.1).

By 2005, the following scenarios are likely to become realities:

- BT-enabled products can forward e-mail received on a cellular phone in a person's pocket to the notebook or laptop computer in his briefcase.
- People can wirelessly download images from digital camera to a PC or cell phone.
- Two cell phones can communicate each other locally like walkie-talkie without having go through base stations.
- A BT laptop can download e-mail via cell phone.
- Synchronized palmtop or laptop devices can access local BT-enabled printers.

- BT can serve as a means of connecting laptop computers or other devices to the public Internet in airport lounges, classrooms, and conference centers through permanent access points (same as IEEE 802.11b WLAN, which will be explained in the next Chapter).
- A laptop user can connect to Internet using the mobile phone as an intermediate to connect to the wide area network locally available.
- A cell phone could wirelessly make connection with a PC to update an on-phone calendar or address book, and then could send information to a company's local area network.

B. BLUETOOTH NETWORK STANDARDIZATION

Typically, the BT protocol stack standardization is shown in Figure 4.2. Shortly, the *RF layer* specifies the system radio communication parameters. The *Base-band layer* specifies the lower-level operations at the bit and packet levels (i.e. Forward Error Correction (FEC), encryption, Automatic Repeat Request (ARQ) protocol etc.). The *link manager (LM) layer* specifies connection establishment and release, authentications, connection and release of synchronous connection-oriented (SCO) and asynchronous connectionless (ACL) channels, traffic scheduling, link supervision, and power management tasks.

The Logical Link Control and Adaptation Protocol (L2CAP) layer has been introduced to form an interface between standard data transport protocols and the BT

protocol. L2CAP handles multiplexing of higher-layer protocols, and segmentation/reassembly of large packets.

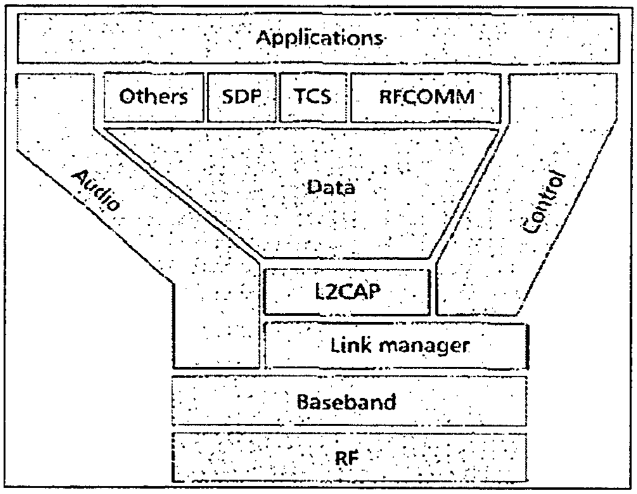

Figure 4.2. The BT protocol stack [From: Ref. 18]

The *data stream* crosses the LM layer, where packet scheduling on the ACL channel takes place. The *audio stream* is directly mapped on an SCO channel and bypasses the LM layer. Between the LM layer and the application, *control messages* are exchanged in order to configure the BT transceiver for the considered application.

Above the L2CAP layer, RFCOMM, *Telephone Control Specification* (TCS), and other network protocols (e.g., TCP/IP, PPP, OBEX, Human Interface Device (HID), WAP) may reside. *RFCOMM* and *TCS* are also specified BT and provide serial cable emulation and cordless telephony protocol, respectively.

SDP is a service discovery protocol, which enables a BT unit to find the capabilities of other BT unit in range. *SDP* discovers which services are available and the characteristics of these services, which can involve common services (e.g., printing, faxing, etc.), as well as more advanced services such as teleconferencing, network

bridging and access points, e-commerce facilities, etc. SDP specifically addresses the BT environment.

Layer-by-layer communications of the protocol stack between two BT-enabled devices are showed in Figure 4.3.

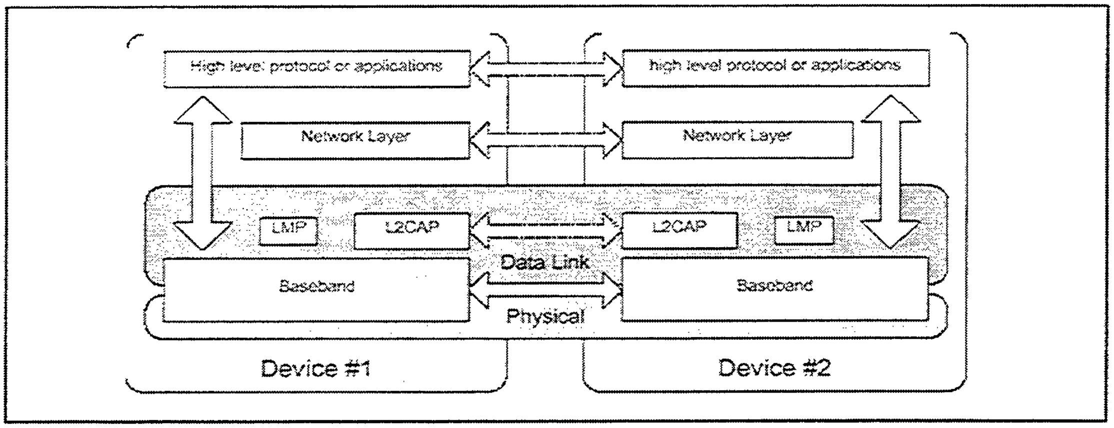

Figure 4.3. Protocol layer-by-layer communications between two BT-enabled devices [From: Ref. 23]

C. AD HOC RADIO CONNECTIVITY

Today, the majority of radio communication systems are based on cellular radio architecture. In this system, a mobile network established on a wired infrastructure, uses one or more base-stations, and must be placed at strategic positions to provide local cell coverage. Users access a portable phone, or more generic mobile terminals, in order to communicate with the other mobile network; the terminals maintain a connection to the network via a radio link to the base stations. There is a strict separation between the base stations and the terminals. Once registered to the network, the terminals are locked to the control channels in the network, and a connection can be established and released according to the control channel protocols. Channel access, channel allocation, traffic

control, and interference minimization are controlled by the base-stations [Ref. 18]. Therefore, the main disadvantages of base stations are not cost-effective, need periodical maintenance, and have restricted coverage area. A most known example is the public radio cellular phone systems like Global System for Mobile Communication (GSM).

On the other hand, in truly *ad hoc* systems, there is no difference between radio units (e.g., there are no distinctive base stations or terminals). Namely, ad hoc connectivity is based on peer communications; any BT-enabled device must be able to connect to any other device. There is no wired infrastructure to support connectivity between portable units; there is also no central controller like base-stations for the units to rely on for making interconnections; nor is there support for coordination of communications. In addition, there is no intervention of operator. For the scenarios envisioned by BT, it is highly likely that a large number of ad hoc connections will coexist in the same area without any mutual coordination; (e.g., tens of ad hoc links must share the same medium at the same location in an uncoordinated fashion). For the BT applications, typically, many independent networks overlap in the same area. This will be called as a scatter ad hoc environment.

At the same time, Scatter ad hoc environments consist of multiple networks, each containing only a limited number of units. The difference among a conventional cellular environment, a conventional ad hoc environment, and a scatter ad hoc environment is illustrated in Figure 4.4.

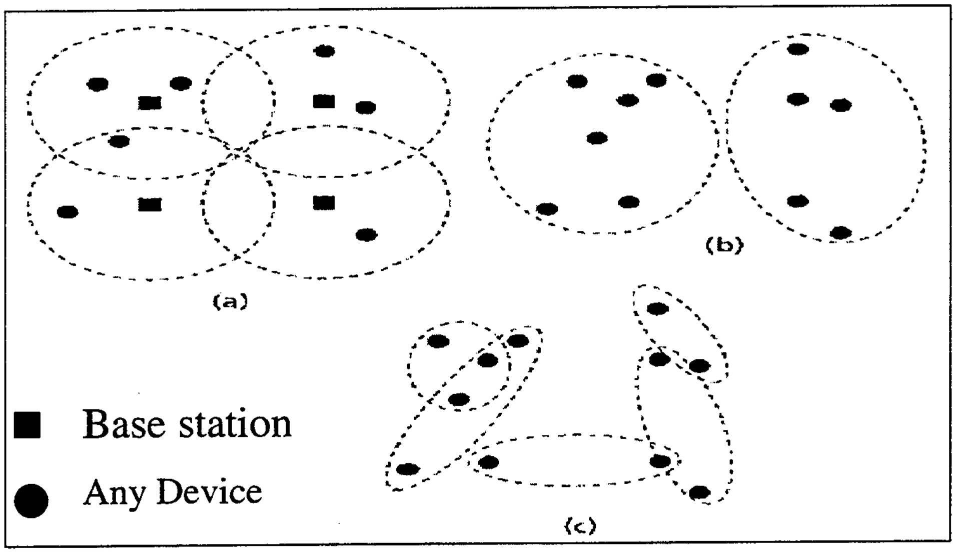

Figure 4.4. Topologies for: (a) cellular radio systems with squares representing stationary base stations; (b) conventional ad hoc systems; and (c) scatter ad hoc systems for BT [From: Ref. 18].

Ad hoc radio systems (e.g., walkie-talkie systems used by the military, police, fire departments, etc.) have been in use for different purposes. However, the BT system is the first commercial ad hoc system destined for a large scale and widely available to the public [Ref. 18].

1. Interpiconet Communication

The BT system has been designed to have tens of piconets operating in the same area without noticeable performance degradation. Multiple piconets in the same area were called as a *scatter ad hoc* above. Therefore, Since BT uses packet-based communication over slotted links; it is possible to interconnect different piconets. However, since the radio can only tune into a single hop carrier, at any given time, a unit can communicate in only one piconet. But the unit can jump from one piconet to another

by adjusting the piconet channel parameters (i.e., by changing the master identity and master clock).

A unit can also change its role when jumping from one piconet to another. For example, a unit can be the master in one piconet at one instant in time, and can be slave in a different piconet another instant in time, or vise versa. One of the scatternet scenarios, which include masters and slaves in different piconet, is illustrated in Figure 4.5. However, by definition, a unit cannot be the master in different piconet because the master parameters specify the piconet FH channel.

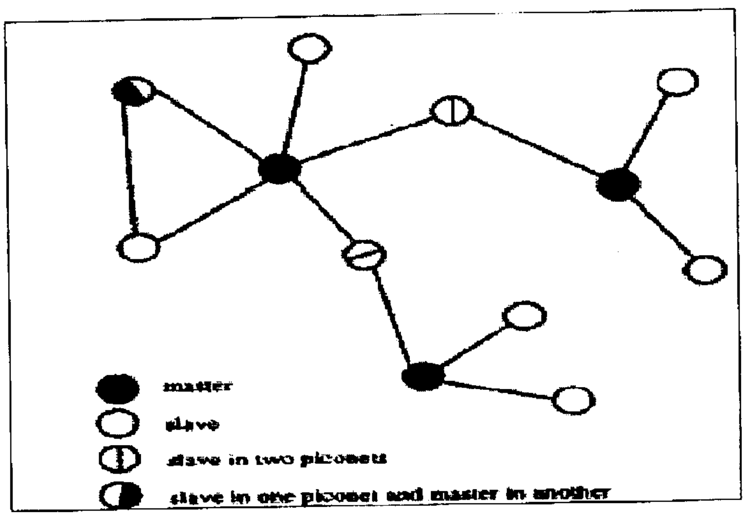

Figure 4.5. Example scatternet showing the masters and slaves roles in different piconets [From: Ref. 28]

D. BLUETOOTH RADIO SYSTEM ARCHITECTURE

In this section, the technological background of BT radio system is presented. Besides, this section describes the design trade-offs made in order to optimize the ad hoc functionality.

1. BT Radio Frequency Spectrum

First, the spectrum that is chosen is open to public without the need for licenses. Second, the spectrum is available worldwide. This radio band, the Industrial, Scientific, Medical (ISM) band, is centered around 2.45 GHz. and was formerly reserved for professional user groups but has recently been opened worldwide for commercial use. Figure 4.6 shows ISM band allocations and hop channel numbers in various countries.

Country	Frequency Range	RF Channels	
Europe* & USA	2400 - 2483.5 MHz	f = 2402 + k MHz	k= 0,...,78
Japan	2471 - 2497 MHz	f = 2473 + k MHz	k= 0,...,22
Spain	2445 - 2475 MHz	f = 2449 + k MHz	k= 0,...,22
France	2446.5 - 2483.5 MHz	f = 2454 + k MHz	k= 0,...,22

Figure 4.6. ISM Band allocations and hop channel numbers in various countries

From the table above, in most countries, frequency spectrum is free form 2400 MHz to 2483.5 MHz. and harmonization efforts are going on having this radio band available truly worldwide.

2. Interference Issue

Since access to the radio band is available to any radio transmitter (as long as transmitter satisfies the FCC regulations), interference immunity is a critical issue. The extent and nature of the interference in the 2.45 GHz ISM band cannot be predicted. Radio transmitters in any environment may range from 10 mW household baby monitors to 100 mW WLAN access points. More of the problems are the high power transmitters for example, microwave ovens and lighting devices. These devices fall outside the power and spreading regulations, but still coexist in the 2.45 GHz band. In addition to

interference from the external devices, co-user interference must be taken into account, which results from other BT users.

There are two techniques to overcome interference immunity. These are interference suppression or avoidance [Ref. 18]. By using coding or direct-sequence spreading interference suppression is obtained. It is taken into account the distance ratios and power differences uncoordinated transmitters. Rather, interference avoidance is more attractive, since the desired signal is transmitted at points in frequency and time where interference is low or absent.

3. Multiple Access Scheme

The selection of the multiple access schemes for ad hoc radio systems is still driven by the lack of coordination and regulations in ISM band [Ref. 25]. However, the Frequency-hopping Code-Division Multiple Access (FH-CDMA) combines many properties, and FH-CDMA is accepted the best choice for ad hoc radio systems. In addition, FH combines the advantage of broadband spreading on average with a narrowband channel instantaneous. On average, the signal can be spread over a large frequency range (80 MHz), but instantaneously only a small bandwidth (1 MHz) is occupied, avoiding most of the potential interference in the ISM band [Ref. 23]. At the same time, the hop carriers are orthogonal, and the interference on adjacent hops can be effectively suppressed by filtering.

Therefore, BT is based on FH-CDMA, in the 2.45 GHz ISM band, a set of 79 hop carriers have been universally defined at 1 MHz-spacing. The channel is a hopping channel with a nominal hop dwell time 625 µs. The BT unit, which is called the *master*,

controls the frequency-hopping channel, the link bandwidth, the symmetry of the traffic, and decides how much piconet bandwidth is given to the other unit. The native clock of the master unit also defines the phase on the sequence. All other participants on the hopping channel are called *slaves* that use the master identity to select the same hopping sequence and add time offset to their respective native clock to synchronize to the frequency hopping channel of master. In time domain, the channel is divided into slots. The minimum dwell time of 625 μs (1600 hops per sec) corresponds to a single slot.

To simplify the implementation of connection among the units, full duplex communications is achieved by applying time-division duplex (TDD), which means that a unit alternately transmits and receive data or voice massages. Separation of transmission and reception in time effectively prevents cross talk between transmit and receive operations in the radio transceiver. Since transmission and reception take place in different time slots, transmission and reception also take place in different hop carriers [Ref. 26].

Figure 4.7 illustrates the FH/TDD channel applied in BT.

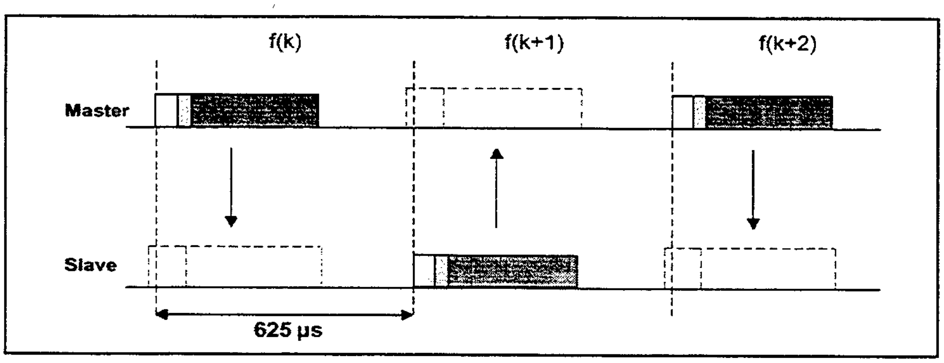

Figure 4.7. An illustration of the FH/TDD channel applied to BT [From: Ref. 23]

4. Medium Access Control (MAC)

BT has been designed to allow a large number of uncoordinated communications to take place in the same area. Therefore, all ad hoc units in range shares the same channel. Each channel serves only a limited number of participants.

A frequency hopping BT channel is associated with a *piconet*. The piconet channel is defined by an identity (providing the hop sequence) and a system clock (providing in the hop phase) of the master unit [Ref. 24]. Typically, each BT radio unit has a free running system or native clock. There is no common timing reference, but when a piconet is established between two or more BT units, the slaves add offsets to their native clocks to synchronize to the master unit; these offsets are released again when the piconet is cancelled.

Different piconet channels have different masters, and this means that each piconet has different hopping sequence and phases. The number of units participating on a common piconet channel is deliberately limited to eight units (one master and seven slaves) in order to maintain a high-capacity link among all the units. This restriction also limits the overhead.

As mentioned earlier, BT is based on peer communications. The master/slave roles are only attributed to a unit for the duration of the piconet. When the piconet is cancelled, the master and slave roles are cancelled. Each unit can become master or slave. By definition, the unit that first establishes the piconet becomes the master. There is only one master in each piconet. A unit can either be master in a piconet or be slave in another piconet and a slave can serve more than one master.

In BT, the master implements centralized control; the master controls the traffic in both the uplink and downlink on the piconet and takes care of access control. Only communication between the master and one or more slaves is possible. The time slots are alternately used for master transmission and slave transmission. For instance, in the master transmission, the master has a slave address of the units for which the information is intended to prevent collisions on the channel due to multiple slave transmissions. For each slave-to-master slot, the master decides which slave is allowed to transmit, and this decision is performed based on a slot-by-slot decision. If the master has information to send to a specific slave that slave is polled implicitly and can return information. If the master has no information to send, this master has to poll the slave explicitly with a short poll packet. Independent collocated piconets may interfere when they occasionally use the same hop carrier. In order to prevent this deficiency, information is transmitted without checking for a clear carrier (no listen-before-talk). For the packet-based communication, if the information is received incorrectly, the information is retransmitted at the next transmission possible slot(s).

5. BT Communication Architecture

The BT system uses packet-based transmission, and the data information stream is fragmented into packets. In each slot, only a single packet can be sent. All the packets have the same format, which is an access code, packet header, and user payload (illustrated in Figure 4.8)

LSB 72	54	0 - 2745 MSB
ACCESS CODE	HEADER	PAYLOAD

Figure 4.8. The format of packets applied in BT

First, the *access code* includes the identity of piconet master. All packets exchanged on the channel are identified by the master identity. The packet will be accepted by the recipient, if and only if the access code of the slave matches the access code of the piconet master. This process prevents packets send by mistake from one piconet to another. The access code consists of a total of a 72-bit information stream.

Second, the *packet header* contains some of the following link control information:

- Three-bit slave addresses to separate the slaves on the piconet –first-address (binary 000) is used for broadcast, for which is sent by the master to all slaves;
- A one-bit acknowledgement/negative acknowledgement (ACK/NACK) for the automatic repeat-request (ARQ) scheme;
- Four-bit packet type code to define 16 different payload types; and,
- An eight-bit header error-check (HEC) code, which is a cyclic redundancy check (CRC) code to detect errors in the header.

The packet header is limited to 18 information bits in order to limit the overhead, and also the packet header is protected by 1/3 rate forward error correction (FEC) coding.

Four control packets are defined in BT system [Ref. 18]:

- The *identification (ID) packet* consists of only the access code in order to use signaling.
- The *NULL packet* has an access code and a packet header, and is used if link control information carried by the packet header has to be conveyed.
- The *POOL packet* is similar to the NULL packet; used by the master to force the slaves to return a response.
- The *FHS packet*: An FH-synchronization packet is used to exchange real-time clock and identity information between the units, so this packet contains all the information to get two units hop-synchronized.

Finally, the remaining 12 type codes in the packet header are used to define packets for synchronous and asynchronous services. These 12 types are divided into three segments. Segment 1 specifies packets, which fit into a single slot, segment 2 specifies a 3-bit slot packet, and segment 3 specifies a 5-slot packet, (illustrated in Figure 4.9). In addition, multi-slot packets are sent on a single-hop carrier, and there is no frequency switch in the middle of a multi-slot packet.

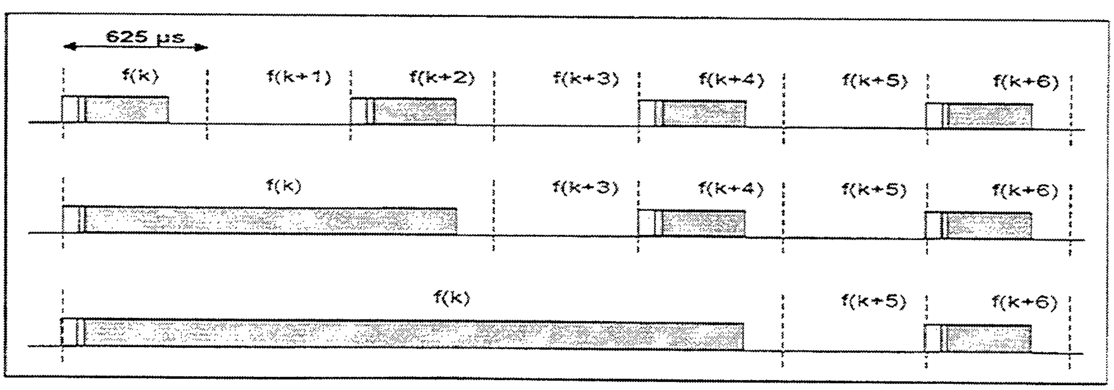

Figure 4.9. The frequency and timing characteristics of single-slot, three-slot, and five-slot packets

6. Physical Link Layer

BT's slotted channels have been defined based on both synchronous (voice message traffic) and asynchronous (data packet traffic) link. Therefore, there are two physical link types: the synchronous connection-oriented (SCO) link (used primarily for voice), and The asynchronous connectionless (ACL) link (used primarily for data packet).

The SCO link is a point-to-point symmetric link between the master and a single slave. In a SCO link, once the connection is established, both master and slave units may send SCO packets without being polled. One of the SCO packet types allows both voice and data transmission. In a SCO link, voice packets are never retransmitted, only the single-slot packets have been defined, and the payload length is fixed.

On the other hand, The ACL link is a point-to-multipoint link (single-slot, three-slot, and five-slot packets) between the master and all the slaves on the piconet. In addition, the ACL link can use all of the remaining slots on the channel not used for SCO links, and the master schedules the traffic over the ACL link. The ACL links support payload with or without a 2/3 rate of FEC coding-scheme.

The maximum user throughput rate that can be obtained over the ACL link is 721 kb/s in one direction and a return link of 57.6 kb/s in the other, or a 432.6 kb/s in both directions as a symmetric link [Ref. 23]. Data throughput is lower than the 1 Mb/s line rate because of the protocol overhead. However, the maximum length of a packet is restricted by the minimum switching time between transmission (TX) and reception (TX), which is specified at 220 μs.

Typically, the slotted structure of the piconet channel of the piconet allows effective mixing of the synchronous and asynchronous links. Figure 4.10 shows an example of a channel with SCO and ACL master-slave links.

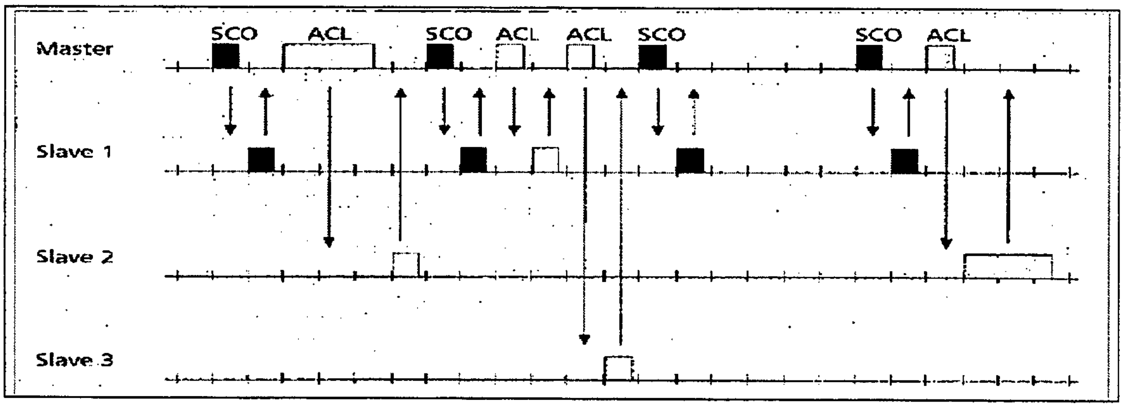

Figure 4.10. An example of mixing synchronous SCO links and asynchronous ACL links on a single piconet channel [From: Ref. 18].

7. Connection Establishment Procedure among the BT units

The connection establishment issue generally includes how units find each other, and how they are defined to support connection establishment [Ref. 23]. There are three types of connection between the units: (1) *Scan*, (2) *Page*, and (3) *Inquiry*. The overall connection establishment procedure is simply illustrated Figure 4.11. Before any connections in a piconet are created, all devices are in STANDBY mode, and a unit in the idle (STANDBY) mode wants to sleep most of the time to save the power.

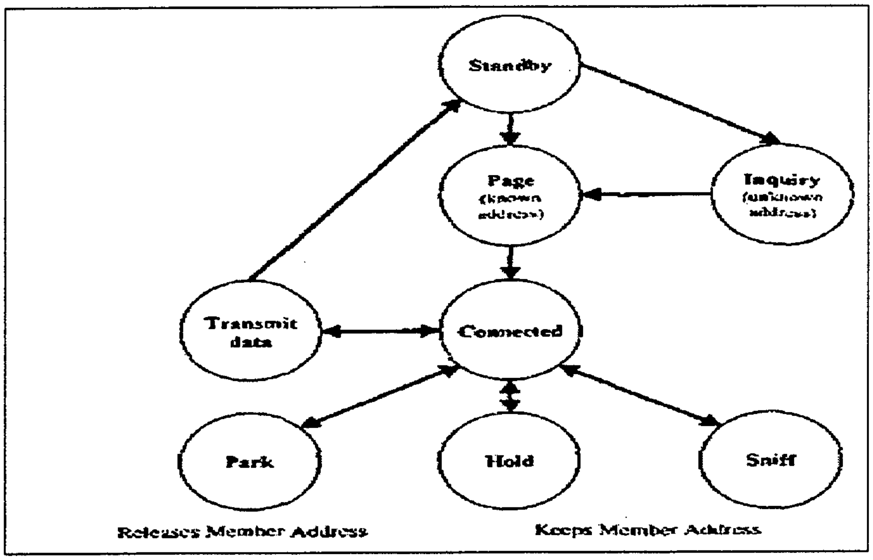

Figure 4.11. Connection establishment procedure in the BT system

a. Scan

For the connections establishment, the unit frequently must determine if other units want to connect. In BT, a unit periodically wakes up listening for its identity. When a BT unit wakes up to scan (The scan time is a little longer than 10 ms.), this unit opens its sliding correlator, which is matched to the access code derived from unit's identity. Every time the unit wakes up, and scans a different hop carrier. The BT wake-up hop sequence is only 32 hops in length, and is a cyclic procedure with a period of 23 hrs. All 32 hops in the wake-up sequence are unique, and type span at least 64 MHz of the 80 MHz available [Ref. 18].

The wake-up sequence is pseudo-random and unique for each BT device. The free-running native clock in the unit determines the phase in the sequence. At the same time, during the idle mode, the native clock is used to schedule wake-up periods. But a trade-off must be made between idle mode power consumption and response time;

increasing the sleep time will reduce power consumption, but will prolong the time before an access can be made.

b. Paging

The unit willing to make connection does not know when the idle unit will wake up and on which frequency. To solve this uncertainty is deliberately placed at the paging. First, we assume that the paging unit knows the identity of the unit to which the paging unit wants to connect. Then it knows the wake-up sequence and can also generate the access code, which serves as the page massage. The pager unit wants to make the connection and the recipient in standby mode that must be susceptible to the page. Apart from the being in range, these units must find each other at the same time and on the same hop carrier. The paging unit then transmits the access code repeatedly at different frequencies. Every 1.25 ms, the paging unit transmits two access codes and listens twice.

Consecutive access codes are transmitted on different hops selected from the wake-up sequence. In a 10 ms time period, 16 different hop carriers are visited, which represent half of the 32 hops wake-up sequences. Then, if the unit cannot find other device, to which the unit must connect, within the next 10 ms period, the other 16 different hop carriers are visited until the unit is found. If the idle unit wakes up in any of these 16 frequencies, this unit will receive the access code and a connection setup procedure follows. However, since the paging unit does not know the phase used by the idle unit, which can equally wake up in any of the 16 remaining frequencies in the 32-hop wake-up sequence [Ref. 18]. The maximum access delay therefore amounts to twice the sleep time.

When the idle unit receives the page massage, it notifies the paging unit by returning a message, which again is the access code derived from the idle unit's identity. Thereafter, the paging unit transmits an FHS packet, which contains all of the pager's information (e.g., identity and clock). This information is then used by both the paging unit and the idle unit to establish a piconet; that is, the paging unit becomes the master using its identity and clock to define the FH channel, and the idle unit becomes the slave.

However, if the units have met before, the paging unit will have an estimate of the clock in the idle unit. When units connect, they exchange their clock information, and the time offset between their free-running native clocks are stored [Ref. 18].

c. Inquiry

To establish a connection, the identity of the recipient is required to determine the page message and wake-up sequence. If this information is not known, (namely, if a pager unit has no identity or wants to discover which units in range) the unit that desires to make a connection may broadcast an *inquiry* message. The inquiry message is typically used for finding BT devices, including public printer, fax machines, and similar devices with an unknown address. Thus, recipients return their address and clock information in order to sync up with pager unit.

With the inquiry procedure, the inquirer can determine which units are in range and what their characteristics are. The inquiry message is an access code, but is derived from a reserved identity (the inquiry address). Idle units also listen to the inquiry message according to a 32-hop inquiry sequence. Units that receive the inquiry message

return an FHS packet, which includes, among other things, their identity and clock information. For the return of the FHS, packet a random back-off mechanism is used to prevent multiple recipients transmitting simultaneously.

8. Error Correction Procedure

In order to maintain a robust and low error rate BT system, there are three error-correction schemes defined [Ref. 23]:

- 1/3 rate forward error correction (FEC) code
- 2/3 rate forward error correction (FEC) code
- Automatic repeat request (ARQ) scheme for data

a. FEC Procedure

The purpose of the FEC scheme on the data payload is to reduce the number of retransmissions. However, in a reasonably error-free environment, FEC creates unnecessary overhead that reduces the throughput. The 1/3-rate FEC code merely uses a 3-bit repeat coding. The 1/3-rate FEC code is used for the packet header, and can additionally be applied on the payload of the SCO link packets. For the 2/3-rate FEC code, a shortened Hamming code is used. This code can be applied on both the payload of the asynchronous packets on the ACL link and payload of the synchronous packets on the SCO link. The FEC code is very simple and fast in encoding and decoding operation, which is a requirement because of the limited processing time between RX and TX.

b. ARQ Scheme

On the ACL link, an ARQ scheme can be applied to the system. In this scheme, the packet retransmission is carried out if the reception of the packet is not acknowledged. In the packet, each payload contains a CRC to check for errors. However, to minimize the complexity, overhead, and wasteful retransmission, BT has implemented a fast-ARQ scheme where the sender is notified of the packet reception in the RX slot directly following the TX slot in which the packet was sent. The fast-ARQ scheme is very efficient, since only failed packets are retransmitted with reduced overhead. The fast-ARQ scheme is illustrated in Figure 4.12.

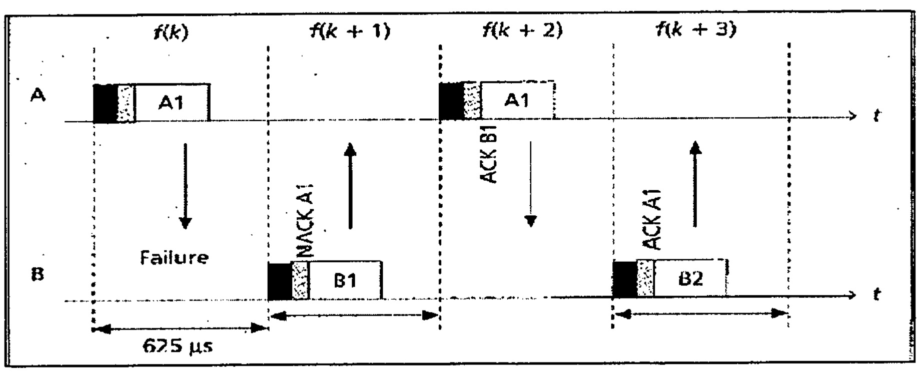

Figure 4.11. An example of retransmission operation in BT based on ARQ scheme [From: Ref. 18]

The ACK/NACK information in the header of the packet received indicate whether the previously sent payload has been correctly received, and thus determines whether a transmission is required or the next packet can be sent [Ref. 23].

9. Power Management issue in BT

In the design of BT, special attention has been placed on reduction of power consumption. For instance, in the idle mode, the unit only scans a little over 10 ms every "t" time where "t" can range from 1.28 to 3.84 sec. A BT slave can be in one of the four operation modes: *ACTIVE, SNIFF, HOLD*, and *PARK*. The last three of these modes are low-power modes [Ref. 23].

In ACTIVE mode, the BT unit actively participates on the channel with the capability of transmitting and receiving data. If an active slave is not addressed for a certain period of time, this slave may sleep until the next new master transmission. A periodic master transmission keep the slaves synchronized to the hop channel, for this, slaves only need the channel access code to synchronize with the master.

In SNIFF mode, the slave does not scan at every master to slave slot, but has a larger interval between scans and the slave can skip some slot just to save power. When a slave is in a sniff mode, master and slave agree on which slots the slave will sniff. Thus, the duty cycle of the slaves is reduced and low bandwidth requires. The master can only start transmission in specific slots. The SNIFF interval is programmable and depends on the application.

In HOLD mode, if no communication is expected for some time, a master can put a slave on this mode. During the hold period, there is no communication possible between a master and a slave. That is, the slaves do not support an ACL link packet on the channel, but the possible SCO links will still be supported. With the HOLD mode, the slaves remain synchronized, but with a predetermined latency. Therefore, The

capacity can be freed to perform other tasks such as, paging, scanning, inquiring, or attending another piconet. At the same time, the unit in HOLD mode can enter low-power sleep mode.

The PARK mode has been defined such that the duty cycle can be reduced even more. However, the PARK mode can be applied after the piconet has been established. The slave can then be parked; that is, this unit only listens to the cannel at a very low duty cycle. The parked-slave must wake up at certain time intervals and listen for an access code and packet header to resynchronize its clock and decide whether this slave can return to sleep. The parked-slave is locked to the master, similar to the way in which cordless and cellular phone are locked to their base stations.

Due to the slave modes as mentioned above, power consumption is minimized in the connection state. If no useful information needs to be exchanged, no transmission takes place. If only link control information needs to be transferred (e.g., ACK/NACK), a NULL packet without a payload is sent.

10. Security

Even though BT is mainly designed for short-range connectivity between personal devices, some basic security elements are included to prevent unauthorized usage and eavesdropping. At the connection establishment level, an authentication process is carried out to verify the identities of the units involved. The authentication process is illustrated in Figure 4.12.

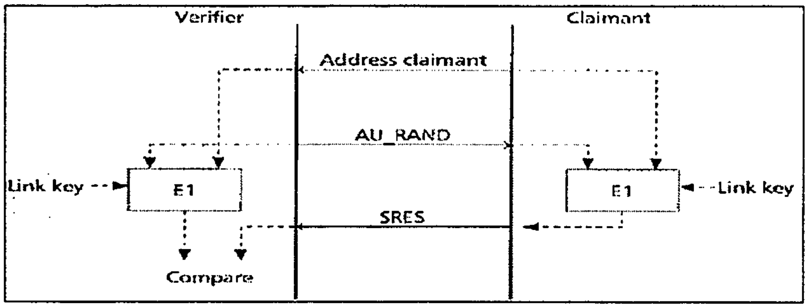

Figure 4.12. The BT authentication procedure

When we summarize the Figure 4.13, on the right, the claimant transmits its claimed 48-bit address to the verifier on the left. The verifier returns a challenge in the form of a 128-bit random number (AU_RAND). The AU_RAND, the claimant address, and a 128-bit common secret link key form the inputs to a computationally secure hash function. El produces a 32-bit signed response (SRES). The SRES produced by the claimant is sent to the verifier, which compares this result with its own SRES. The challenger will continue with connection establishment, only if the two calculated SRES numbers are the same.

In addition to the 32-bit SRES, The E1 algorithm produces a 96-bit authenticated cipher offset (ACO), which is used in the encryption procedure. The payload information is XOR-ed with a cipher sequence (it has enable and disable mode options). To prevent eavesdropping on the link, the payload of each packet is encrypted.

BT provides a limited number of security elements at the lowest layer. More advanced security procedures (e.g., public keys, certificates) can be implemented at higher layers (e.g., application layer, etc).

11. Summary

The goal of this Chapter is to show to readers what the BT radio system specifications are, how the system works, and what the design limitations and restrictions are today. BT is a new technology, still under development.

On the basis of the BT radio system specifications, I developed the "*wireless world*" MAS simulation toy model, which will be introduced more detailed in the Chapter VII. In my model, I focus on the basic performance issues of the BT radio system in different experiment conditions. Such as, system frequency band utilization, dropped packet rates, different transmissions type –data, and voice, interference effects of the microwave oven, IEEE 802.11b WLAN systems, concrete blocks (walls), and different weather conditions, connection establishment delays, power-consumption, etc. I implemented the BT system by using MAS and GA that are the two new ways to develop a robust, more realistic, and cost-effective adaptive system.

V. IEEE 802.11B WIRELESS LANS (WLAN)

A. INTRODUCTION

Over the past decade, the desire to provide universal connectivity for mobile computers and communication devices is fueling a growing interest in wireless networks. This growth will be more visible in the next decade. To satisfy the needs of wireless data networking, study group 802.11 was formed under IEEE project 802 to recommend an international standard for *Wireless Local Area Networks* (WLANs). WLAN offers the user a degree of mobility never thought possible in a conventional LAN environment [Ref. 37].

An alternative to Bluetooth, a wireless LAN IEEE 802.11b, which is actually follow-on project of 802.11, is a data transmission system that uses radio waves rather than a cable infrastructure, and provides location-independent wireless network access between computing devices introduced by The Institute of Electrical and Electronics Engineers (IEEE) [Ref. 21]. In addition, IEEE 802.11b specifications allow WLAN products to deliver Ethernet-quality data rates of up to 11 Mbps for portable devices and PCs within outdoor and indoor environments. With IEEE 802.11b, WLANs will be able to achieve wireless performance and throughput comparable to wired Ethernet. A network topology of IEEE 802.11b is illustrated in Figure 5.1.

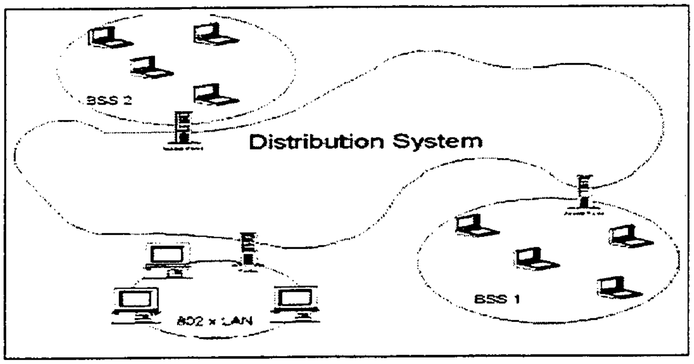

Figure 5.1. IEEE 802.11 Network Topology [From: Ref. 35]

WLANs give freedom to users that provides anytime and anywhere network access. This freedom offers numerous user scenarios for a variety of work environments, such as:

- Immediate access to patient information for doctors and hospital staff;
- Easy, real-time network access for on-site consultants or auditors;
- Improved database access for traveling supervisors (e.g. production line managers, warehouse auditors, or construction engineers);
- Simplified network configuration for temporary setups such as trade shows or conference rooms;
- Faster access to customer information for service vendors and retailers;
- Location-independent access for network administrators, for easier on-site trouble-shooting and support; and,
- Real-time access to study group meetings and research links for students.

B. IEEE 802.11B TECHNOLOGY ARCHITECTURE

In 1999, the IEEE published the 802.11b amendment to the 802.11 standard by adding two higher speeds (5.5 and 11 Mbps). The goal of the new standard was to

provide robust and reliable performance five times faster than the original standard. Due to these 5.5 and 11 Mbps higher speed, IEEE 802.11b WLANs, mobile users can get Ethernet levels of performance, throughput, and availability. Typically, the 802.11b standards focus on the bottom two layers of the ISO model, the physical layer and data link layer (Figure 5.2).

The 802.11b specification affects only the physical layer, adding higher data rates and more robust connectivity [Ref. 21].

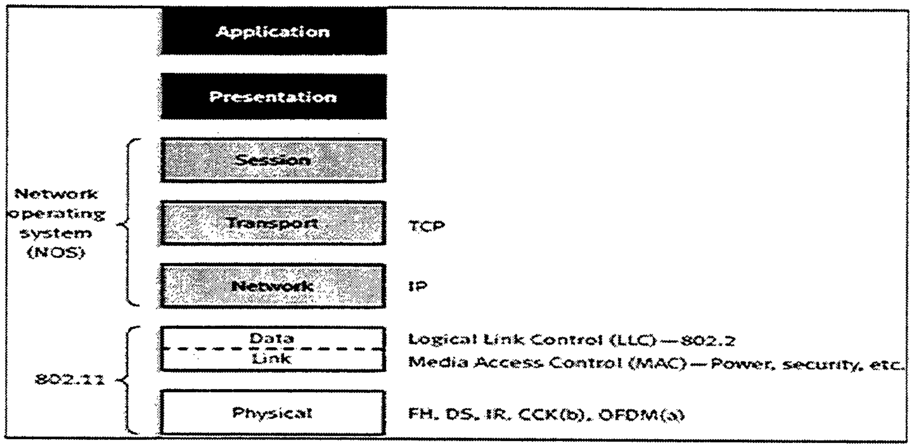

Figure 5.2. 802.11b and the ISO Model [From: Ref. 21]

1. IEEE 802.11b Operating Modes

802.11b is comprised of two pieces of equipment: a *wireless station*, (which is usually a PC equipped with a wireless network interface card), and an *access point (AP)* [Ref. 21]. The AP acts as a bridge between the wireless and wired networks, and usually consists of a radio, a wired network interface, and bridging software. The AP acts as the base station for the wireless network, aggregating access for multiple wireless stations onto the wired network. The 802.11b standards define two modes: an *infrastructure mode* and *ad hoc mode*. In the infrastructure mode (illustrated in Figure 5.3), the wireless

network consists of at least one access point connected to the wired network infrastructure and a set of wireless end stations, (e.g. IEEE 802.11b laptops, notebooks, PCs, palm systems, etc).

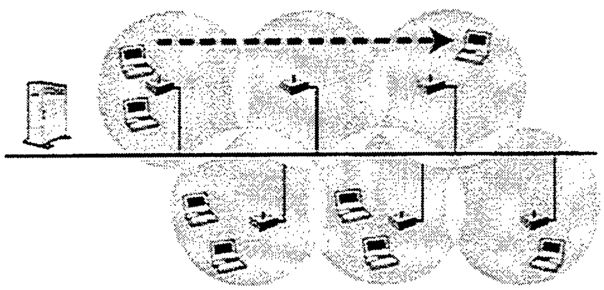

Figure 5.3. WLAN Infrastructure mode

The Ad hoc mode (Figure 5.4) is simply a set of 802.11b wireless stations that communicate directly with one another without using an access point or any connection to a wired network. This mode, featuring architecture similar to that used by Bluetooth, is useful for efficient set up of a wireless network anywhere that a wireless infrastructure does not exist, or is not required for a hotel room, convention center, or airport etc.

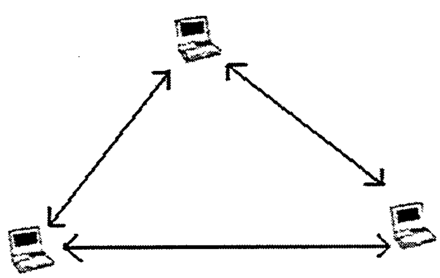

Figure 5.4. Ad-hoc Networking

2. THE IEEE 802.11B Physical Link Layer

Similar to BT, IEEE 802.11b WLAN operates on ISM frequency band ranges between 902-928 MHz and 2.4 - 2.484 GHz, which do not require Federal Communication Commissions (FCC) license. The physical layer of 802.11b originally includes two spread-spectrum radio techniques and a diffuse infrared specification. Spread-spectrum techniques, in addition to satisfying regulatory requirements, increase reliability, boost throughput, and allow many unrelated products to share the spectrum without explicit cooperation and with minimal interference [Ref. 21]. The original wireless 802.11 standard defines data rates of 1 Mbps and 2 Mbps via radio waves using frequency hopping spread spectrum (FHSS), which explained in detail in the previous Chapter, or direct sequence spread spectrum (DSSS).

In the DSSS technique, 2.4 GHz band is divided into totally 14, 22 MHz bandwidth channels across 83.5 MHz of spectrum. Data is sent across one of these 22 MHz channels without hopping to other channels. On the other hand, to compensate for noise on a given channel, a technique called "chipping" is used. Each bit of user data is converted into a series of redundant bit patterns called "chips."

The key contribution of the 802.11b addition to the wireless LAN standard has been support of two new speeds, 5.5 Mbps and 11 Mbps by interoperating with 1 Mbps and 2 Mbps speeds [Ref. 21]. In order to obtain these high speeds, the DSSS had to be selected as the only physical layer data transfer technique for the standard since, as noted above, FHSS cannot support higher speeds without violating current FCC regulations.

In order to increase the data rate in the 802.11b standard, advanced coding techniques are employed. For this, 802.11b specifies Complementary Code Keying (CCK), which consists of a set of sixty-four 8-bit code words. For instance, the 5.5 Mbps rate uses CCK to encode 4 bits per carrier, while the 11 Mbps rate encodes 8 bits per carrier.

To compensate very noisy environments as well as extended range, 802.11b WLANs use *dynamic rate shifting* (DRS), allowing data rates to be automatically adjusted to handle for the changing nature of the radio channel. Ideally, users connect at the full 11 Mbps rate. However when devices move beyond the optimal range for 11 Mbps operation, or if substantial interference is present, 802.11b devices will transmit at lower speeds, falling back to 5.5, 2, and 1 Mbps. If the device moves back within the range of a higher-speed transmission, the connection will automatically speed up again.

3. The 802.11b Media Access Control (MAC)

The data link layer of 802.11b consists of two sub-layers: Logical Link Control (LLC) and Media Access Control (MAC). Within these two layers, a key part is the MAC protocols. Given the growing popularity of real-time services and multimedia-based applications it is critical that the 802.11 MAC protocols be tailored to meet their requirements. The 802.11 MAC layer protocol provides *asynchronous, time-bounded, and contention free access control* on a variety of physical layers. MAC layer of the IEEE 802.11b is unique, and handles many functions in a WLAN system. The MAC layer serves as the interface between the physical link layer and the host device. In an 802.11b WLAN, collision detection is not possible due to what is commonly referred to

as the near/far problem –to detect a collision, a station must be able to transmit and listen at the same time, but in radio systems, the transmission and receive operations carry out in different time slot.

Therefore, IEEE 802.11b uses a slightly modified protocol known as Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). This protocol attempts to avoid collisions by using explicit packet acknowledgment (ACK), which means an ACK packet is sent by the receiving station to confirm that the data packet arrived intact [Ref. 27].

CSMA/CA process works as follows. For instance, a station wishing to transmit senses the air, and, if no activity is detected, the station waits an additional, random length period of time, and then transmits if the medium is still free. If the packet is received intact, the receiving station sends an ACK frame that, once successfully received by the sender, completes the process. If the ACK frame is not detected by the sending station, either because the original data packet was not received intact or the ACK was not received intact, a collision is assumed to have occurred, and the data packet is retransmitted after waiting another random amount of time. However, it does add some overhead to 802.11b, so that an 802.11b will have slower performance than an equivalent Ethernet LAN.

Finally, the 802.11b MAC layer provides for two key features to provide robustness of the system, these are cyclic redundancy check (CRC) checksum and packet fragmentation [Ref. 21]. Each packet has a CRC checksum calculated and attached to ensure that the data was not corrupted in transit. This is different from Ethernet, where higher-level protocols such as TCP handle error checking. Packet fragmentation allows

large packets to be broken into smaller parts when sent over the air, which is useful in very busy environments or when interference is a factor, since larger packets have a better chance of being corrupted. This technique reduces the need for retransmission in many cases and thus improves overall wireless network performance.

4. IEEE 802.11b Connection Establishment

The 802.11b MAC layer is responsible for the way in which a wireless client station use a radio modem to communicate with a so-called "*access poi*nt" (AP). For example, when an 802.11b client enters the range of one or more APs, the client chooses an AP to associate with, based on signal strength and observed packet error rates [Ref. 21]. Once accepted by the AP, the client tunes into the radio channel to which the AP is set. Periodically the client surveys all 802.11b channels in order to assess whether a different AP would provide better performance characteristics. If the client determines that this is the case, it reconnects with the new access point, tuning to as the same radio channel as the access point.

Reconnection usually occurs because the wireless station has physically moved away from the original access point, causing the signal to weaken. In other cases, reconnection occurs due to a change in radio characteristics in the building, or due to high network traffic on the original access point.

In a typical environment, two or more APs will provide signals to a single client. The client is responsible for choosing the most appropriate access point based on the signal strength, network utilization and other factors. When a station determines the existing signal is poor, this station begins scanning for another access point. The client

can do this process by passive listening or active probing each channel and waiting for a response. This process of dynamically associating and reconnection with APs allows network managers to set up WLANs with very broad coverage by creating a series of overlapping IEEE 802.11b cells throughout a building or across a campus.

5. Time-Bounded Data Support

Time-bounded synchronous data such as voice and video is supported in the 802.11b MAC specifications through the *Point Coordination Function (PCF).* As opposed to the Distribution Coordination Function (DCF), which provides to avoid collisions over the medium, and where control is distributed to all stations, in PCF mode a single access point controls access to the media. In PCF function, the point coordinator assigns priority to each client in a given transmission frame. If a BSS is set up with the PCF enabled, time is spliced between the system being in PCF mode and in DCF (CSMA/CA) mode [Ref. 27].

When the system is in PCF mode, the AP will poll each station for data, and after a given time, move on to the next station. No station is allowed to transmit unless it is polled, and stations receive data from the AP only when they are polled. Since a PCF gives every station a turn to transmit in a predetermined fashion, maximum latency is guaranteed. A downside to PCF is that it is not particularly scalable, in that a single point needs to have control of media access and must poll all stations, which can be inefficient in large networks.

6. Power Management

Unlike Bluetooth, The 802.11b supports power conservation to extend the battery life of portable devices. The standard supports two power-utilization modes, called *Continuous Aware Mode* and *Power Save Polling Mode* [Ref. 21]. In the former, the radio is always on and drawing power, whereas in the latter, the radio is "*dozing*" with the AP queuing any data. So the clients on the network wake up on a regular period and listen for a special packet called a TIM (traffic information map) from the AP. In between TIMs, the client shuts off his radio and thus conserves power. All the devices on the network share the same wake-up period, as they must all wake up at exactly the same time to hear the TIM from the AP. The TIM informs certain clients that they have data waiting at the AP. A client card stays awake when the TIM indicates the client has messages buffered at the AP until those messages are transferred, and then the card goes to sleep again.

7. Range and Throughput

IEEE 802.11b communicate using radio waves because these waves are transmitted many indoors structures or can reflect around obstacles. WLAN throughput depends on several factors, including the number of users, micro-cell range, interference, multi-path propagation, standards support, and hardware type. Of course, anything that affects data traffic on the wireless and wired portions of the LAN, such as latency and bottlenecks.

802.11b lets portable devices connect to corporate networks or the Internet over distances as great as 300 feet [Ref. 20]. But the range changes based on interference, environment, and line traffic.

C. SUMMARY

This Chapter highlights the basic specifications of the IEEE 802.11b WLAN system, how the system works, and what the robustness and weaknesses of the system are. IEEE 802.11b WLAN is an alternative radio system to BT. IEEE 802.11b and BT are the two leading wireless technologies today, and share common frequency in the 2.45 GHz ISM band. Typically, IEEE 802.11b WLAN is older technology than the BT, has higher transmission range, and faster data throughput rate. Even though IEEE 802.11b are used in the market today, it is still under development, and needs improvement especially on the data throughput rate.

Nonetheless, in my wireless world model, I would not implement the specifications of the whole IEEE 802.11b WLAN system. Instead I used IEEE 802.11b WLAN technology as an interference system to the BT. Basically the interference depends on the transmission distance between WLAN and BT-enabled devices, and devices' transmission power levels in the simulation environment.

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VI. BLUETOOTH VERSUS IEEE 802.11B WLAN

A. INTRODUCTION

Bluetooth (discussed in detail in Chapter IV) is a standard for very low-powered, low-cost, small-sized and short-range wireless radio connections that would link personal access devices (PDA) (cell phones, desktop, laptops, palm pilots, etc), and give these devices Internet access. BT's 1.0-version specifications were completed in 1999.

On the other hand, IEEE 802.11b, (discussed in detail in Chapter V), is a standard for a WLAN covering both physical and media access control (MAC) layers that is modulated on carrier radio waves. IEEE 802.11b is a high rate extension to the original 802.11, and can operate on 5.5 to 11 Mbps data rates. IEEE 802.11b uses only DSSS technology and CCK (Complementary Code Keying) modulation to achieve its high data rates. Nevertheless, the standard of the next generation, IEEE 802.11a, also known as HiperLAN2, will operate in a new band of frequencies at 5 GHz, and achieves as high data rates as high as 54 Mbps. [Ref. 20].

The two technologies were originally conceived with slightly different purposes in mind. But as each grows more sophisticated, and today, a lot of money and efforts are focused on both technologies. Typically, IEEE 802.11b WLAN and BT can be described as complementary rather than competitive. BT is said to be more mobile-centric than 802.11b WLAN. For example, while 802.11b enables limited mobility within offices and campuses, BT supports global roaming capabilities.

B. COMPARISON OF BT AND IEEE 802.11B IN SOME ASPECTS

1. Range

BT is designed to use very low transmission power. Maximum transmission range will be around 10 m. But, later versions may allow longer ranges. High-powered BT would extend the range to 100m. However, since IEEE 802.11 is designed to be used in office buildings and in a campus, the transmission range is around 15-150 m indoor and 300 m outdoor.

2. Bit Rates

First, as discussed in Chapter IV and V, IEEE 802.11b WLAN is clearly faster than BT. However; BT's hop frequency (1600 hops/second) is very high when compared to the radio frequency usage of WLAN IEEE 802.11 (2.5 hops per second). The high hop frequency limits the maximum length of the data transmission. Therefore, A BT channel cannot handle data throughput as high as does IEEE 802.11 WLAN, and the overhead of switching between the frequencies could cause some delay, and affect the throughput [Ref. 20].

A BT node can send data at a 1 Mbps rate, which is shared with the devices at the same piconet. In BT, asymmetric or symmetric data connections to the devices are allowed. An asymmetric data rate of 721Kbps and symmetric data rate of 432.6 kbps in both directions is possible according to BT specifications. So, it is often suggested that

BT's data throughput is around 721 Kbps, but BT's actual data rate is closer to 30 to 400 kbps in practice.

In contrast, the original IEEE 802.11 network cards can transfer data at rates from 1 to 2 Mbps. IEEE 802.11b is introduced having 5.5 to 11 Mbps gross data rate performance [Ref. 21]. However, the real throughput is close to 4-5 Mbps. Above all, the new IEEE 802.11a will support data gross rates from 24 to 54 Mbps.

3. Radio Output Power

BT uses very low transmission power, about 1mW, which allows reasonable range up to 10 m. However, BT specifications permit increasing the transmission power to 100 mW due to the user needs, and then the BT devices could operate over distance as great as 100 m [Ref. 18]. However, WLAN IEEE 802.11b has 1W antennae in USA and 100mW antennae in Europe, and then IEEE 802.11b devices could operate over distance as great as 300 m.

4. Security

Data-Link Layer and Physical Layer of both technologies obviously have very weak security. According to [Ref. 21], the high hopping frequency used in BT transmissions is said to provide protection against eavesdropping; however, since the hardware address defines the used hopping frequencies, catching only one packet of a transmission is needed for a malicious listener to synchronize their devices. As stated in [Ref. 20], BT uses 4 LFSR (Linear Feedback Shift Registers) to encrypt link level data and thus further enhance security. The security setup for a BT connection is established

in the software layer. So, an inexperienced or careless user can reduce the level of security down to almost zero.

Contrarily, IEEE 802.11b networks are based on an absence of privacy, since the AP in the system is acting as a hub in a wired network. The basic nature of a hub is that AP repeats all packets, which receives in the network. The IEEE 802.11b standard includes an optional encryption capability WEP (Wired Equivalent Policy), which can be implemented in MAC [Ref. 20]. The passwords are stored in the APs and on each portable device. WEP encrypts the transmissions between the AP and the portable devices. All the devices use the same password in a network. Obviously the encryption does not provide for much security in a public network, since IEEE 802.11b devices would have to publish the password.

5. Interference Immunity and Robustness

The 2.4 GHZ ISM radio frequency band is a broad, free and unlicensed spectrum space. That is an advantage that attracts the designers of other portable devices. But all of their inventions have the potential to interfere with each other. In this radio frequency band, BT uses much lower transmission power than IEEE 802.11b. So, more powerful devices may easily interfere BT enabled devices' transmissions.

802.11b direct sequence high rate devices are very reliable in the presence of transmitting BT products. However, BT users should avoid transmission within 50 feet of 802.11b radios and APs, since BT transmissions cause interference [Ref. 22].

BT may be able to handle interference by using its narrowband fast-frequency-hopping scheme that uses pseudo random-hop pattern and short data packets. BT's high

hopping rate at 1600 (hops per second) can help BT evade interference and tolerate noise that could swamp IEEE 802.11b. Further, as mentioned in detail in Chapter 3, the use of forward error correction (FEC) decreases the number of needed retransmissions by adding redundant data to the data stream [Ref. 20].

Still, interference can cause problems for a mobile laptop user using devices that follow both the IEEE 802.11b and BT standards. At device's circuit level, data cannot possibly be transferred using both specifications at the same time, since they are utilizing the same radio frequencies, and shielding them from each other disturbance may not be possible. That may place limitations on the coexistence of the standards.

6. Costs and Future

In the next few years, the transmission power of BT is expected to allow devices to operate in a range that is ten times wider than that of the first prototypes. Further, the bandwidth is anticipated to be greater, therefore allowing higher data rates. The BT's 2.0 version specifications will likely increase the data rate to 2 Mbps.

Although the initial cost of the WLAN is higher than BT, the costs of IEEE 802.11b WLAN are decreasing. For instance, the cost of wireless LAN cards will drop below $50, and as low as $5 in the next few years [Ref. 20]. At the same time, Ericsson representatives state that it is unlikely that BT chips will cost only $5. Today, the cost of the chip is around $27, and might drop to about $10 by 2003.

C. SUMMARY

This Chapter typically highlights the similarities, differences, and cost issues of both IEEE 802.11b standard and BT system on the basis of the design aspect. Then, the Chapter concluded that IEEE 802.11b standard is better suited to wireless local area networks. It is faster and provides for a wider range of use. On the other hand, BT's natural ad hoc connectivity results in fewer necessary configurations, and gives good usability in many new applications. BT can withstand noisy data channels batter than IEEE 802.11b. It is not easy to say, if security of either of them is better. Because security varies a lot, depending on the user selections

Typically, the wireless world model is based on the BT system, and IEEE 802.11b WLAN system is just used as interference to BT.

VII. WIRELESS WORLD DESIGN PARADIGM AND ARCHITECTURE

A. INTRODUCTION

This Chapter of the thesis introduces the "*Wireless World*" design paradigm and architecture. The background material presented in the previous Chapters serves as a basis for developing a MAS and GA model to explore the BT radio system. The following sections provide a broad explanation of the algorithms and methods used to build the framework.

Wireless world is a simple two-dimensional (2D) toy model of Bluetooth Technology (BT) developed by using MAS and GA. The model is implemented in the Java programming language version 1.2.1 and Borland jbuilder3 university edition editor environment. In the wireless world system, MAS are focused on a population of agents. In order to make the simulation more realistic, primary BT system specifications are simulated in the wireless world environment.

In addition, the model is designed for an outdoor environment in which there are six different weather conditions, and three types of interference systems. The IEEE 802.11b WLAN, an alternative to the BT, is implemented as an interference system in the simulation environment, that is, 802.11b WLAN negatively affects the BT system performance, mainly proportional to the transmission distance between two devices.

The main goal of the wireless world model is to establish a BT piconet in which there are at most seven slaves, and a single master device with the other interference

devices, such as microwave oven, IEEE 802.11b, etc., then, to measure the system performance according to the different experimental settings defined by the user.

B. WIRELESS WORLD SYSTEM ARCHITECTURE

The system architecture of the wireless world simulation is based on two main layers, and performance measurements (illustrated in Figure 7.1). These two layers are:

- The Infrastructure Layer, and
- The Demand Generator Layer

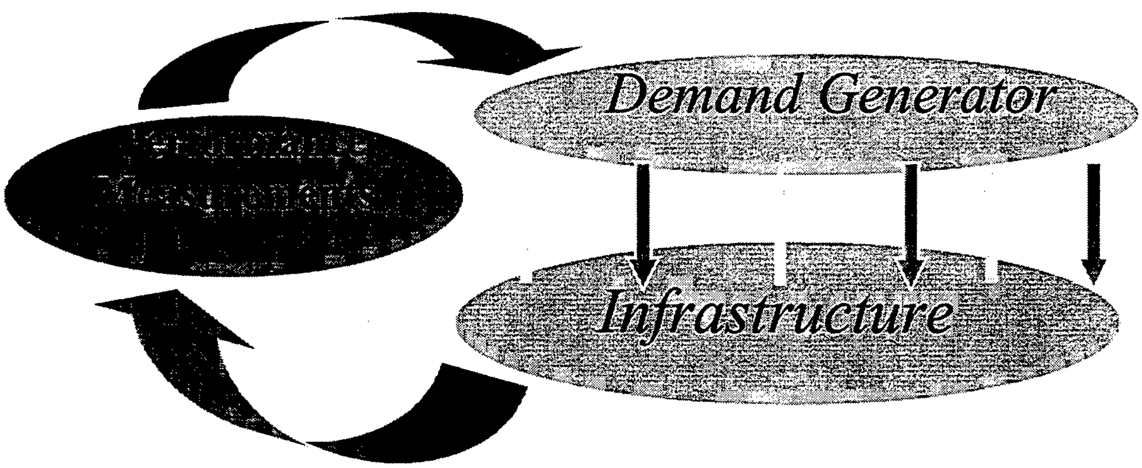

Figure 7.1. The Wireless World Simulation system architecture

My main motivation to define two structure layers is to make a distinction between the BT system specifications and operating phase of the system, and to organize and simplify the implementation of the whole design. Therefore, after finishing the entire infrastructure implementation of the BT and interference systems, to drive and to organize the system is very easy with respect to various kinds of experimental conditions

and overheads. Contrarily, beginning the both layers at the same time is very hard to implement and time consuming.

1. Infrastructure Layer

The infrastructure layer (IL) is implemented as Multi-agent System (MAS). As mentioned more detailed in Chapter II, MAS are composed of six components:

a. Environment

The *environment* of a MAS simulation is the situated or non-situated space in which all objects, and/or agents, exist. Rather than thinking of the environment as landscape or terrain, think of it as the collection of objects and agents that interact with each other. The MAS environment can be a 2D or 3D space in which the agents can act and the objects are situated. In the wireless world model, a user can access the simulation by way of a 2D Graphical User Interface System (GUI).

In the wireless world simulation environment, the user may create BT-enabled agent devices, IEEE 802.11b WLAN access points and their peripheral client devices, microwave ovens, and wall structures. The user can dynamically change the positions of every object or agent from one place to another.

Additionally, the model is simulated in the outdoor environment, and for the six different weather conditions: (1) Normal weather (no interference effect on the radio transmission), (2) Fog, (3) Slow-rain, (4) Heavy-Rain, (5) Snow, (6) Storm (highest degree of interference). Each weather condition affects the system performance with different probabilities. Since the BT radio system is designed for 10 meters maximum transmission range with the low power consumption of 1 mW, and 100 meters maximum

transmission range with the high power consumption of 100 mW, the simulation environment consists of 930 by 700 pixels, and 25-pixel represents one-meter distance.

The main *paint* Java method used throughout the program is located in the *SimulationEnv* class. This method is the common Java method used to draw the visual graphical entities. *SimulationEnv* class calls the draw method of every agent to display the agents and objects.

b. Agents

Agents, explained more detailed in Chapter II, are autonomous, computational entities having intelligence and intrinsic behaviors that can be viewed, as perceiving their environment through sensors and acting upon their environment through effectors. Agents have ways of gathering information or sensing about their environment and adapt the actions based on their characteristics.

In the wireless world model, separate Java classes are used to create the six different agents, each of which can be BT or IEEE 802.11b-enabled devices depending on the user's desire (see Figure 7.2. and Figure 7.3.). These agents are:

- *Cell phone agent* –can work with either BT or IEEE 802.11b due to the user selection.
- *Laptop agent* –can work with either BT or IEEE 802.11b due to the user selection.
- *Palm pilot agent* –can work with either BT or IEEE 802.11b due to the user selection.

- *Personal Computer agent* –can work with either BT or IEEE 802.11b due to the user selection.
- *Printer agent* –can work with only BT without user intervention.
- *Fax agent* –can work with only BT without user intervention.

These six agents are defined in two different characteristics such as *passive agents* –printer and fax, and *active agents* –cell phone, palm pilot, PC, and laptop. Main difference between these two types of agent is that passive agents can only be slave by definition of BT piconet, but active agents can be either master or slave.

On the other hand, each agent has identical or different intrinsic attributes that lead to one of the most insightful capabilities of the simulation. Different combinations of attributes can often result in many different outcomes, or system performances during a simulation run. In the simulation environment, the user can easily move an agent from one location to his or her desired location by pressing and holding on the left mouse button, while the mouse arrow is on the desired agent.

Additionally, in order to change the initial attributes of any agent such as transmission power type, slave mode, slot type power, or making connection with IEEE 802.11b WLAN access point, etc., the user can open the agent attribute dialog box (see Figure 7.3.) and can change any mode that he or she wants by using the radio buttons, or combo boxes. In order to open the agent attribute dialog box, the user only needs to click on the left mouse button, while the mouse arrow is on the appropriate agent.

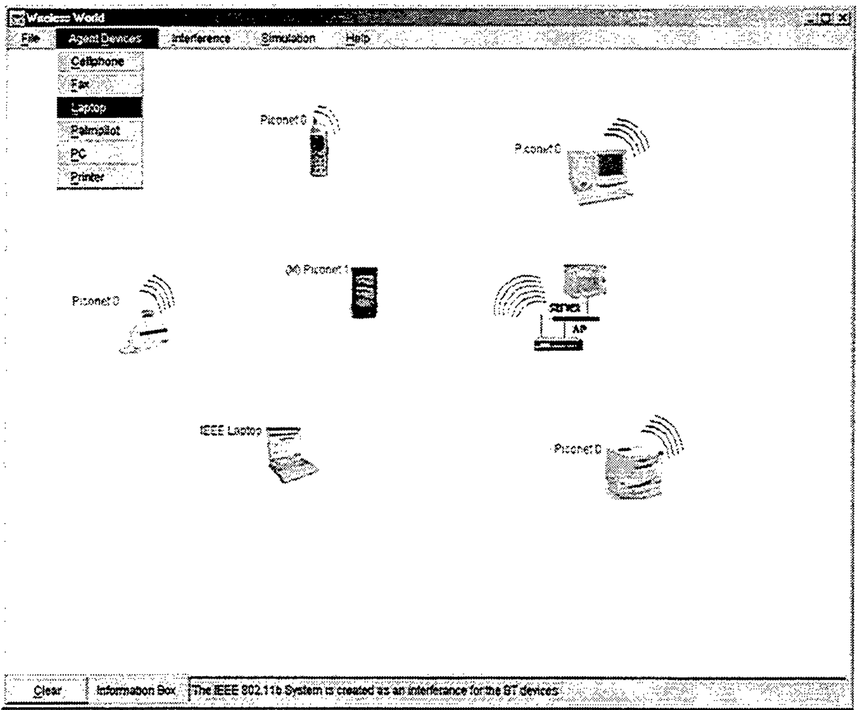

Figure 7.2. BT-Enabled or IEEE 802.11b-enabled Agents

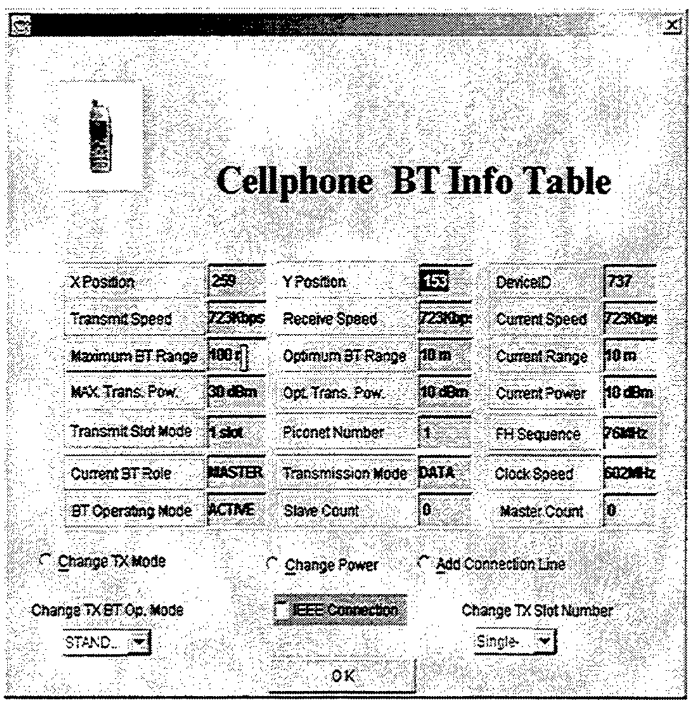

Figure 7.3. Cell phone Agent Attribute Dialog Box

Each agent has certain types of goals that are embedded in the agent at the beginning of the simulation. For example, a master agent can send data or voice packets to a slave agent, and if this is a data packet, it may be single slot, or three-slot, or five-slot packet. During the master-to-slave, or slave-to-master transmission, only the same frequency hop channel is used, after establishing the connection between the two devices.

c. Objects

Objects are defined, as computational entities that encapsulate some state, are able to perform actions, or methods on this state, and communicate by massage passing [Ref. 14]. Objects do not exhibit control over their behaviors. So, they do not have intelligence and intrinsic behaviors.

However, objects are the base-level entities in the environment. All agents in the environment are also objects, or things. Objects have the ability to represent themselves, either two-dimensionally (2-D) or three-dimensionally (3-D), or simply as text strings. Objects also have the ability to update themselves over time [Ref. 30].

In the wireless world environment, three types of objects are defined as being interference to the BT system. These objects are:

- *Wall object* –blocks radio transmission between master and slave. Wall is a passive object, which has no active interference effect. Degree of Interference depends on the location of wall, and to the degree of being closeness to the other devices (see Figure 7.4).
- *IEEE 802.11b WLAN access points and their peripheral clients* (see Figure 7.4.) –make interference to BT piconet. Within the

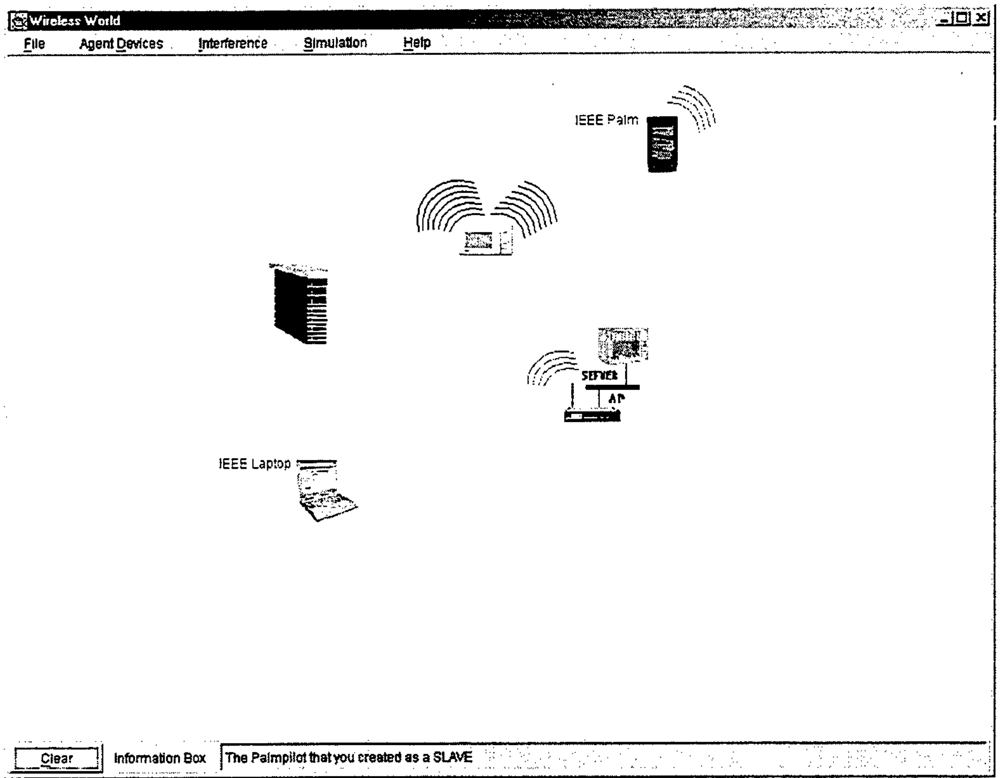

Figure 7.4. IEEE 802.11b WLAN configuration in the environment

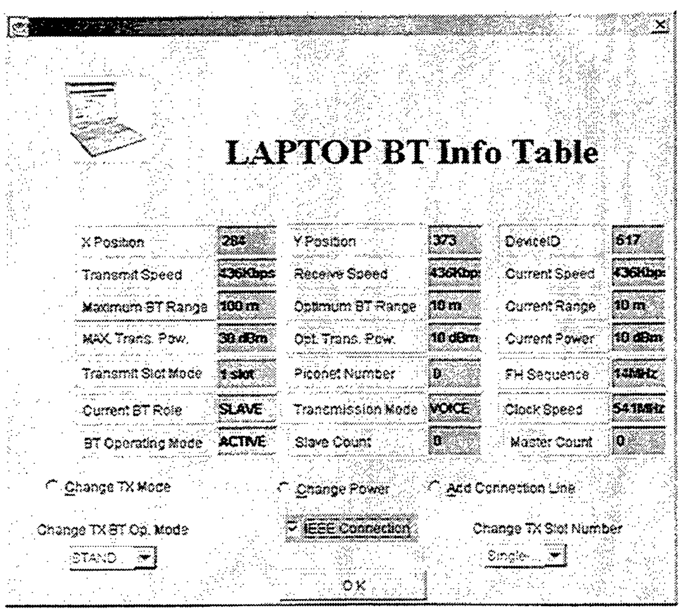

Figure 7.5. Connection establishment procedure between laptop agent and IEEE 802.11b access point

d. Relations

Relations are an inevitable result of the MAS. Because it is always possible to happens that there are a number of interactions between an agent and an object, or an agent and another agent during a simulation run.

In the *wireless world model*, there are the relations connecting or binding agents to each other that result in the assignment of new roles, goals, and responsibilities. Shared resources and abilities often allow the individual agent to satisfy a goal it would otherwise not be able to achieve. The agent needs to sense the appropriate agents and/or objects necessary to form the relationship. The goal is determined by a number of factors including the personality of the agent, the feedback from the environment on the state of achieving each goal, and any outside influences that may encourage one goal be given a higher priority than another. If more that one rule is provided to accomplish the same goal, some form of credit assignment is used to indicate which rules are more successful than others. In this manner, genetic algorithms can be used to improve the agents rule set overtime.

Therefore, a number of relations are defined among BT-enabled agent devices, or between agent and object. First of all, communication procedure of piconet is the main relation between the BT-enabled devices (master and slaves). Piconet starts with first connection establishment of the master with another slave device, ends with canceling the piconet by the master device. Data or voice packet transmission (communication) between master and slave agent devices is another relation during the simulation run.

e. Operations

Normally, *Operations* (illustrated in Figure 7.6.) are the means by which an agent causes effects (interacts) in its environment. Operations include sensors and operators. This can be thought of operators as the Input/Output (I/O) methods for an agent. When designing agents for MAS, the developer needs to consider what sensing abilities they should be capable of, as well as what operators or actions they can employ. These effectors can be specifically type-matched to the goal/rule pairs for ease of implementation [Ref. 30].

Each agent device perceives or senses each object or the other agents in the simulation environment. During the packet transmission, master and slave devices checks the other devices' operation mode, distances, and positions, and weather condition. Then slave or master receives or drops the packet.

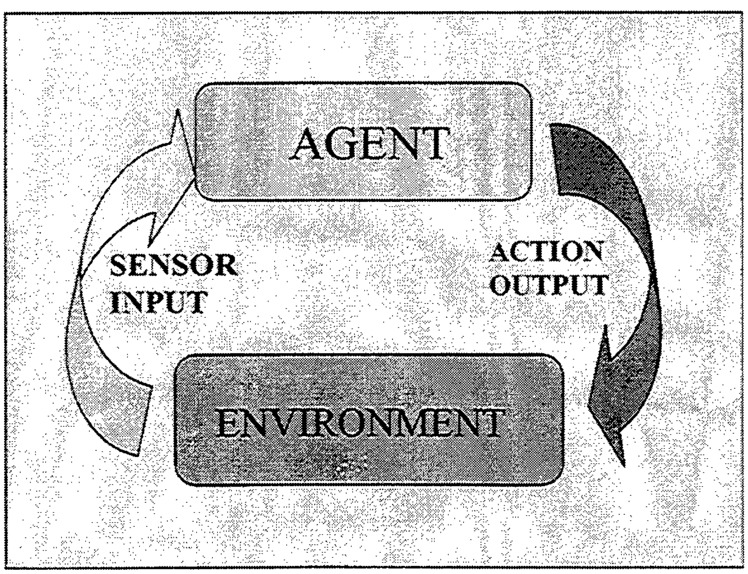

Figure 7.6. Typical agent operation procedure

f. *Laws*

Laws are the limitations and restrictions in the specified environment placed on the agents and objects in the environment. Ferber refers to laws as the "reaction of the world to (attempts) at modification" [Ref. 5]. Laws are not necessarily specified as a concise set of rules that must be complied with. More often, laws are intertwined into the simulation [Ref. 30].

In the wireless world model, each BT-enabled agent obeys the rules. According to the BT specifications, some of the basic rules are implemented in the wireless world simulation, and are listed below:

- Piconet consists of master and slaves, and each agent can be a master or a slave due to the user selection with the exception of fax and printer agent, which has to always be slave.
- In order to establish a piconet, the master agent (cell phone, palm pilot, PC, or laptop) sends an inquiry message to a slave, which has to scan and accept this inquiry massage.
- There are only one master, and at least one or at most seven slaves in a piconet.
- Only one piconet is possible in the wireless world simulation in order to simplify the model.
- Slaves may operate on the following power saving mode (1) Hold, (2) Sniff, (3) Park, or normal operation mode (Active).
- There is no more than one slave-to-master or master-to-slave transmission at a time in the piconet.

- The master controls all the communication traffic.
- Only data or voice communication is possible between the master and the slave.
- In data communication, multi-slot (single slot, three-slot, or five-slot) packets may be allowed, but in voice communication, if and only if, single-slot packet is allowed.
- If the data packet drops with any reason, the same packet has to resend the designated device using the packet acknowledgement procedure. But in voice communication, there is no packet retransmission.
- Any agent device is able to make transmission in two power modes, which are low-power mode (1 mW), and high-power mode (100 mW). Initially every device is on low power mode, but this mode can be changed by the user.
- If no communication exist in the specific time interval, all the master and slaves go to sleep for power saving.
- Each simulation run lasts 6000 time steps.

2. Demand Generator Layer

Demand Generator Layer (DGL) is actually the driver layer of the wireless world simulation controlled by a single thread in the executable *BluetoothDemandManger* java class. Additionally, DGL employs a Genetic Algorithms (GA) in order to explore the

performance limitations and restrictions of the BT system, and to search the better and worse performance results. GA are different from the traditional algorithms in four ways:

1. GA work with a coding of the parameter set (direct manipulation of coding), not the parameters themselves.
2. GA search from population of points, not a single point.
3. GA use fitness (objective) function (search via sampling), not derivative or other auxiliary knowledge.
4. GA use probabilistic transition rules, not deterministic rules.

Additionally, many computational problems require a computer program to be adaptive that continue to perform well in a dynamic environment. In this context, GA provides a strong alternative to simple random variation and selection models.

In the wireless world model, six different genes are defined for the GA:

- Job Arrival distribution –two types of which are Poisson process, and equal interval time;
- Weather conditions –six types of which are normal, fog, slow rain, heavy rain, snow, and storm;
- Slot-type –three types of which are single-slot, three-slot, and five-slot data transmission;
- Fixed Payload size –five types of which are 45, 90, 120, 450, 600 slots
- Transmission Type –two types of which are data, or voice;
- Number of job –any number between the numbers of slaves. However, the number of job equals to at least one, or at most the numbers of slaves.

In DGL, given a clearly defined problem to be solved and a bit string representation for candidate solutions, GA work as follows:

1. Simulation starts with a randomly generated population of 90 six-bit chromosomes.

2. The fitness (objective) function of each chromosome is calculated in the population. Objective function calculation is depicted in Equation 7.1. In the wireless world system, objective function defines to maintain best results. Simply, when the master utilization increase, the error rate increases in the system, so there is a positive correlation between error rate (dropped packets) and master time utilization with respect to the slot type and the number of jobs. As a result, more error rate is more problem in the performance, in contrast lower error rate means having a robust system.

$$Of = (U_{MT} + Err) / (ST + Jn)$$

Of : Objective Function is determined by a system's ability to survive, and the other obstacles to adulthood and subsequent reproduction.

U_{MT} : Master device time slot utilization during a single simulation run.

Err : Number of dropped packet error rate during a single simulation run.

ST : The number of concurrent job

Jn : The number of job

Equation 7.1. Objective function calculation

3. This procedure repeats the following steps until 90 offspring have been created.

- Number of concurrent job –one or more job is concurrently going on at the same time interval.
- Total number of dropped packet –according to slot type, shows how many packets dropped during a run.
- Error rate –shows how many times packet dropped during a simulation run (see Figure 7.7).
- Master or slave transmission count –every packet transmission of master or slave devices is counted by the system.
- Master or slave receiving count –every packet reception of master or slave devices is counted by the system.
- Master or slave sleep time –out of the transmission, every master and slave devices goes to sleep for power saving, and sleep times are counted by the system.
- Master time slot utilization –transmission and reception percentage of master devices proportional to total run time (see Figure 7.9).

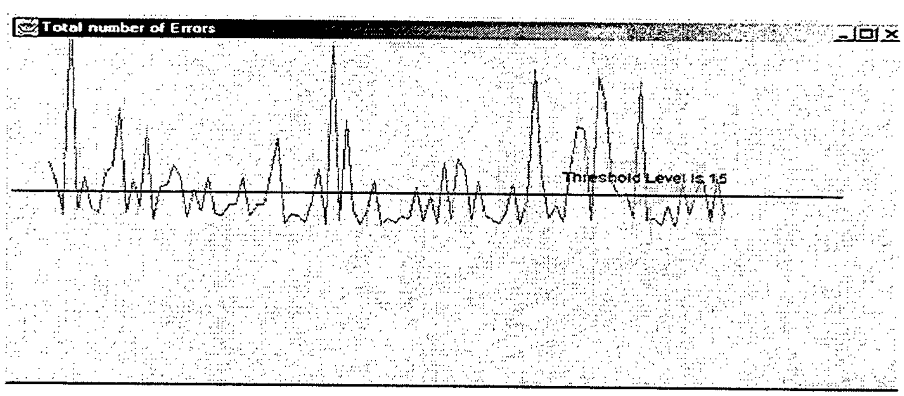

Figure 7.7. Total Number of error for the population of 100 chromosomes

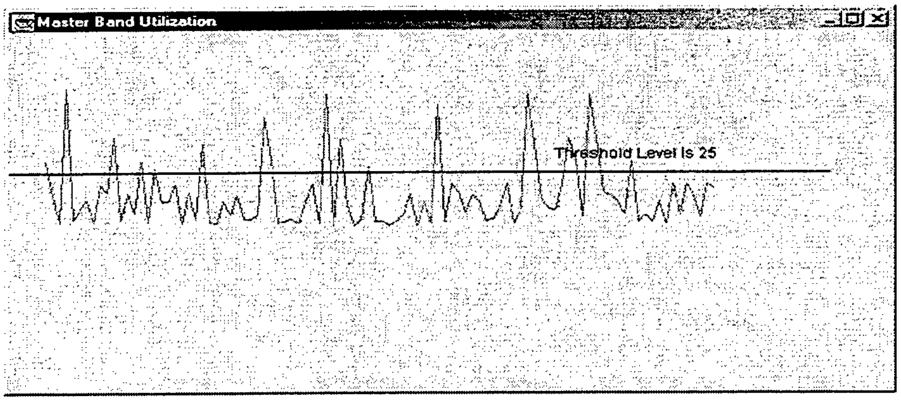

Figure 7.8. Master time slot utilization for the population of 100 chromosomes

C. RUNNING THE WIRELESS WORLD SIMULATION

The wireless world simulation program can be started by running the *WirelessWorld* Java main (executable) class in the jbuilder3 editor environment. When the program is started, the blank GUI frame window (simulation environment) appears on the screen (illustrated in Figure 7.9). Pressing the "OK" button on information box, the system is ready for the user system configuration. The first goal of the user is to establish a BT piconet by choosing the devices from the six different *Agent Devices* menu items. During the device selection procedure, the user can define any active device as a master. After the master is defined, a 2D GUI text appears on the top left side of the device, which exhibits a piconet number, and that the selected device is master. After defining the master, the other selected devices automatically become slaves or IEEE 802.11b clients.

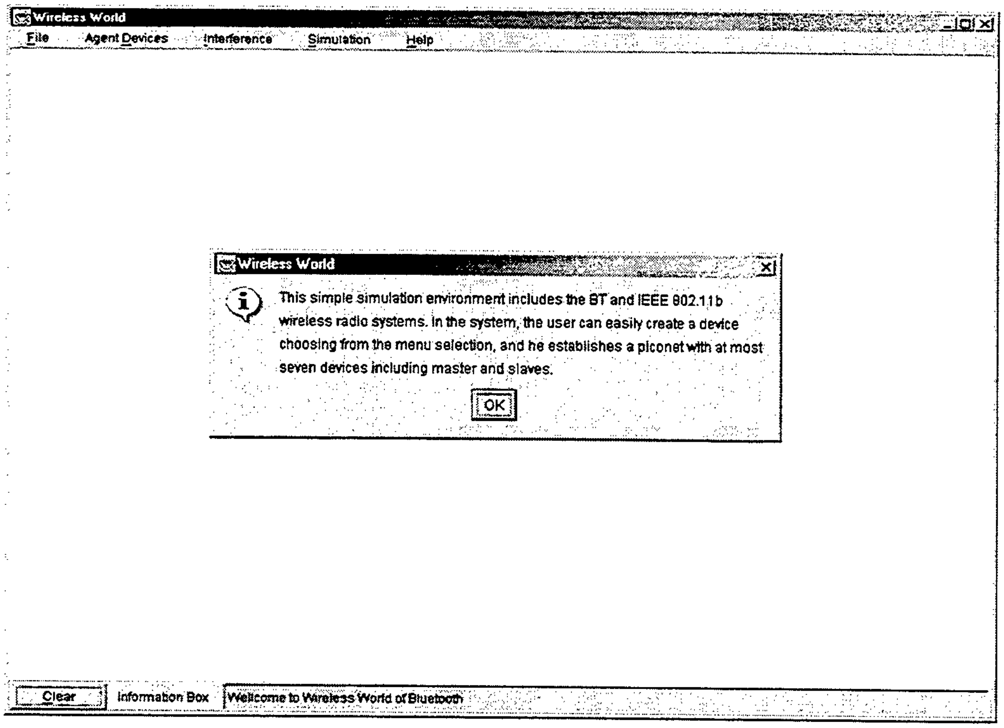

Figure 7.9. Blank wireless world simulation environment

Two mouse action events are defined in the wireless world system:

- Left mouse button –As long as the mouse arrow are on any device, when the user clicks and holds on the left mouse button, he or she can dynamically change the x and y coordinate of this device by dragging the mouse to anywhere in the simulation environment.
- Right mouse button – As long as the mouse arrow are on any device, once the user clicks on the right mouse button, agent attribute dialog box instantly opens. Then the user can see and change some of the attributes of the agents based on the different configurations.

On the other hand, if a device is master, in order to send a inquiry messages, and establish a piconet including slaves, user has to follow a few steps. First, clicks on the right mouse button, selects *add connection line* radio button on the agent attribute dialog

box. Second, an information box pops up; the user presses the "OK" button to close the information box. Third, a connection line appears on the master device, after all the user cannot change the coordinate of the master instead move the line to make connection with the other devices. Finally, the user press on the top of the line, and drags the mouse and release the right mouse button if the mouse arrow is on the designated device in the simulation environment. Repeating the last step, user can establish a piconet including at most seven slaves.

After the piconet establishment, user can create as many interference devices or wall structures as he or she desires. And he or she can place these objects on anywhere he or she wants. An example of user-defined wireless world system configuration is depicted in Figure 7.10.

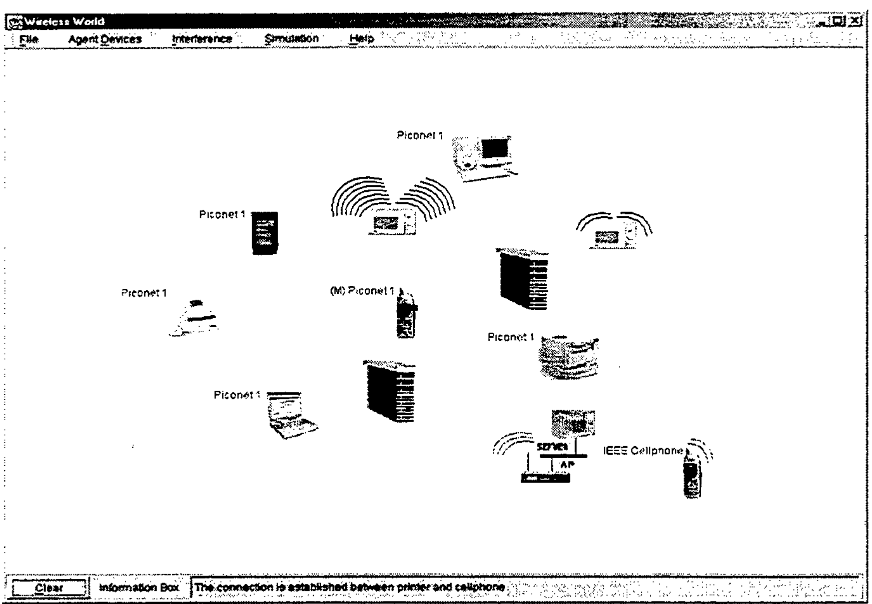

Figure 7.10. A user-defined experimental configuration

After finishing the configuration of environment, user can run the simulation by pressing on *run* item in the *Simulation* menu list (run, stop, and continue). Eventually,

after finishing run by the system, the results are showed the user with the text information and graphical displays (see Figure 7.8, Figure 7.9, Figure 7.11, and Figure 7.12.).

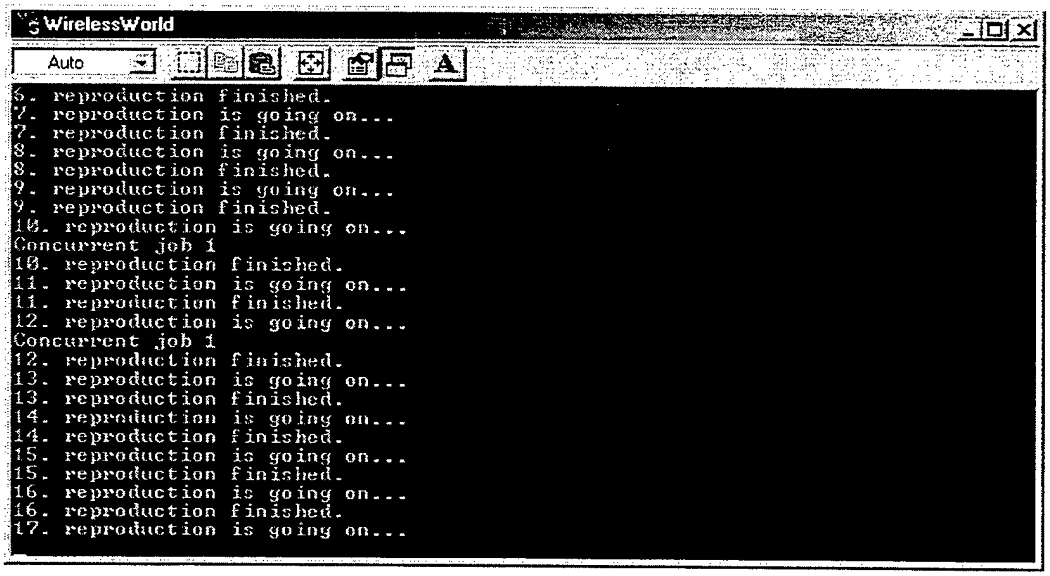

Figure 7.11. Running simulation

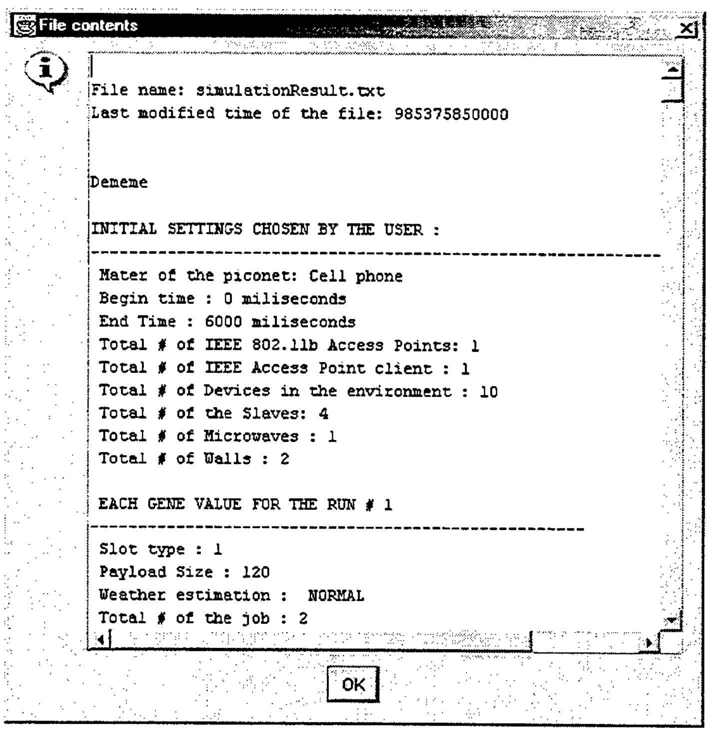

Figure 7.12. Text results of the simulation

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VIII. WIRELESS WORLD DESIGN ANALYSIS AND SOME RESULTS

A. INTRODUCTION

This Chapter investigates the usefulness and potential of the two-layer model by using this model to analyze the effects of an experimental configuration. In this experiment, I try to find and verify that load conditions that cause the Infrastructure Layer to suffer poor performance. In other words, the Demand Layer is doing its job when load conditions cause poor performance in the Infrastructure Layer.

This thesis aims at demonstrating the feasibility of using two coordinated MAS systems, arranged in layers, to explore the performance limit of a network protocol, such as Bluetooth. Follow on work could use this thesis to explore and document the performance conditions and boundaries of an actual protocol in detail.

This Chapter will present data created by the two-layer system simulation and then analyze that data to verify that the demand layer is able to drive the Infrastructure layer into performance problems.

B. RESULTS AND ANALYSIS

This section introduces the area of investigation, the agent and the system characteristics, and the experiment used throughout this Chapter's analysis. The general configuration chosen for this experiment includes most of the agent communication device types, and all the interference devices and wall structures. Under different load

conditions, this configuration was able to produce good, low-error rate performance, and it also produces runs with serious performance problems. That is, from the experiment results, we can see that the Demand Layer did its job.

The experiment's system configuration is illustrated Figure 8.1. The experimental environment consists of one BT piconet including one master, which is the cell phone, and five slaves, which are PC, Palm pilot, fax, and printer. Additionally, there are one active microwave oven, one active IEEE 802.11b access point and its two peripheral devices including a laptop and a Palm pilot, and two wall structures, which are placed on blocking the master-to-slave transmission in maximum level. To simplify the experiment, all the slaves are working in active mode, not in the power-saving mode. Also, all master and slave devices, and IEEE 802.11b clients are working on low-power (1 mW) and optimum range mode (10 meters).

A microwave oven is included in environment because it works with BT in the same frequency band of 2.45 GHz with a high power transmission. And it has a spectacular negative effect on the performance of the BT system.

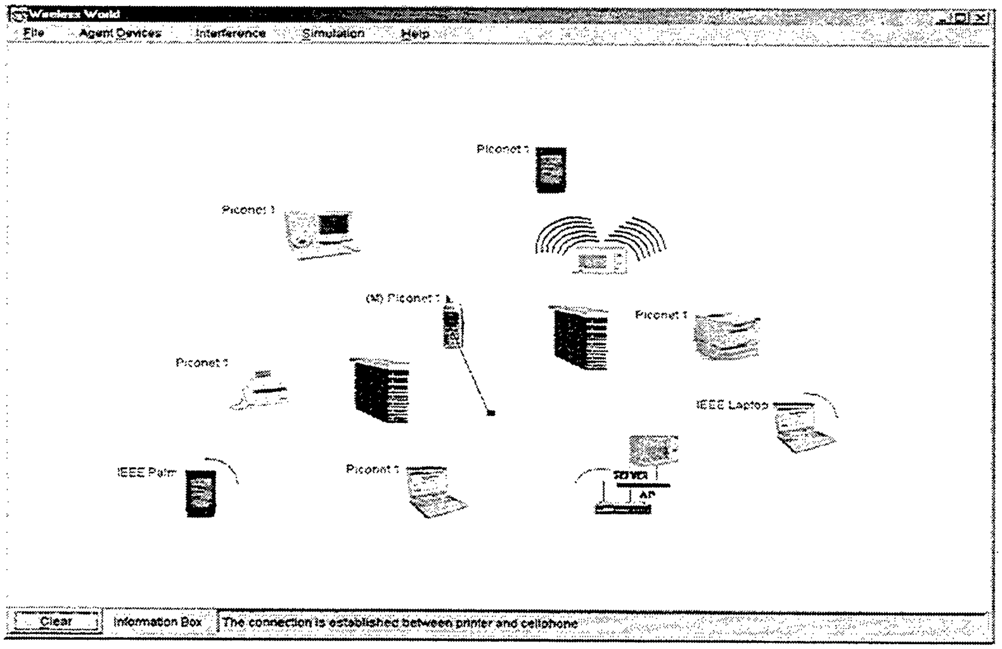

Figure 8.1. The experimental environment

In this experiment the simulation runs for 20 generations. A generation consists of 90 simulation runs based on one set of demand parameters (i.e., one chromosomes that contains six genes). Each run produced different kind of results, due to the different gene combinations that drove the Demand layer. The experiment produced both measurements that revealed bad and good performance. In a robust wireless system environment, high error rate and large number of dropped packets are always unwanted. Normal performance would exhibit low error rate and low dropped packet rates. Therefore, to explore the performance limits, the Demand layer drives the Infrastructure Layer for 1800 iterations in each 20 generations. Each run produces performance output that is used to select the most demanding load specifications. , And we got some results. In Table 8.1, the gene combinations and some performance measurements values are shown for poor performance scenarios. Similarly, in Table 8.2, the gene combinations

and some performance measurements values are shown for the good performance scenarios.

Gene Values						Performance Measurements			
Slot	**Payload**	**Weather Type**	**# of Job**	**TX type**	**Dist. Type**	**Drop Packet**	**Error Rate**	**Master Time Util.**	**Concur Job**
1	600	Fog	5	Voice	Poisson	69	69	60	2
1	600	Heavy Rain	4	Voice	Equal Interval	63	63	60	2
1	600	Snow	4	Voice	Equal Interval	66	66	60	1
1	600	Light Rain	4	Data	Equal Interval	51	51	42	2
1	450	Snow	5	Voice	Poisson	54	54	45	2
5	450	Snow	4	Data	Equal Interval	110	22	38	0
1	450	Light Rain	5	Voice	Poisson	40	40	45	2
3	600	Light Rain	3	Data	Equal Interval	47	19	41	3

Table 8.1. Bad performance measurements for the Experiment

Gene Values						Performance Measurements			
Slot	**Payload**	**Weather**	**# of Job**	**TX type**	**Dist. Type**	**Drop Packet**	**Error Rate**	**Master Time Util.**	**Concur. Job**
5	45	Normal	5	Voice	Equal Interval	0	0	1	0
3	45	Snow	1	Data	Poisson	0	0	1	0
3	120	Normal	1	Data	Equal Interval	3	1	3	0
5	45	Normal	1	Data	Equal Interval	5	1	1	0
1	90	Heavy Rain	1	Voice	Poisson	5	5	3	0
1	45	Fog	3	Voice	Poisson	2	2	9	0
3	90	Snow	2	Data	Equal Interval	1	3	3	0
3	45	Heavy Rain	4	Data	Poisson	0	0	4	0

Table 8.2. Good performance measurements for the Experiment

To maintain a better performance result in the wireless world environment, packet size, number of concurrent jobs, slot type, and number of job play key roles. In particular, the payload size and slot type are the most important parameters because when the packet size increases, the system is more likely to drop the packet in a high interference environment. In Figure 8.2, over the iteration of 90 runs for the first generation total error rate results are demonstrated. Similarly in Figure 8.3 and Figure 8.4, master time slot utilization and the number of concurrent jobs are shown respectively.

For example, according to the following figures, we measured poor performance measurements with a maximum level of 66 errors under the 60 percent master time slot utilization. In contrast, we measured good performance measurements with the minimum level of zero errors under the three percent master time slot utilization. Also, different performance measurement levels are spread over the iteration of 90 runs because of different demand levels and random process. As seen from the Figure 8.2 and Figure 8.4 high, medium, and low load conditions are used by the demand layer.

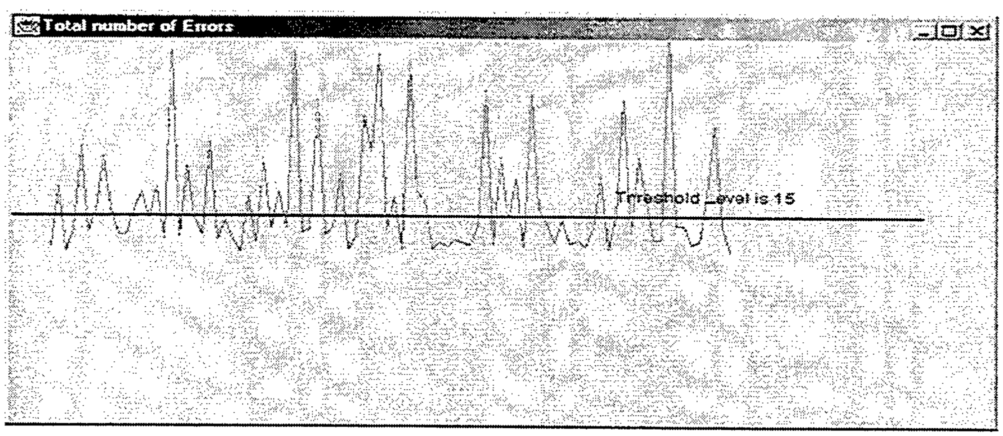

Figure 8.2. First generation system total error rates for 90 experimental conditions

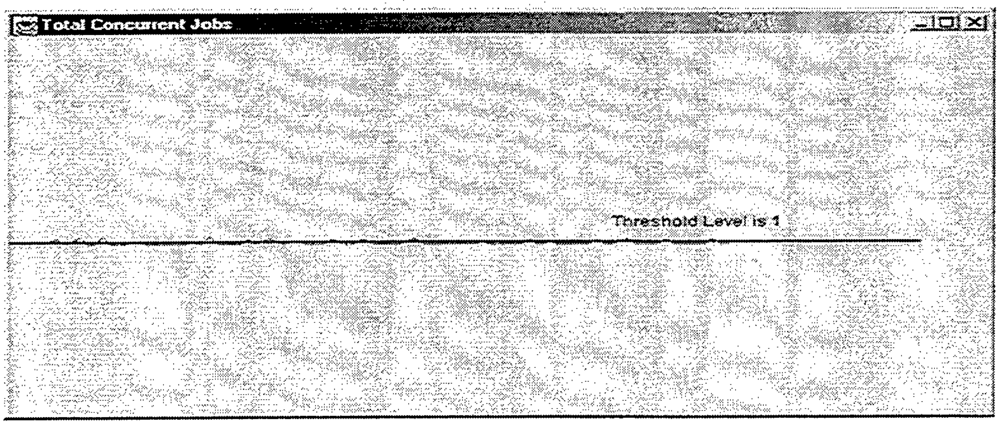

Figure 8.3. Total concurrent jobs for 90 experimental conditions

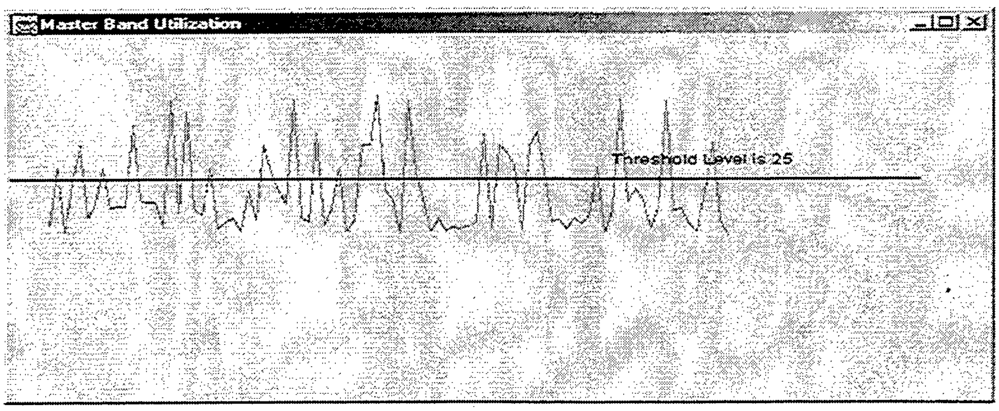

Figure 8.4. Master time utilizations for 90 experimental conditions

Usually, in all the worst cases, the packet sizes (600, 450 etc.) and the number of jobs (1 or more) are very large, and slot types are very low (single slot). On the other hand, the numbers of concurrent jobs are not more than three because it depends on the number of slaves and distribution type. For the Poisson process, it is more likely to have more than one concurrent job.

Even though the first generation uses the randomly assigned gene combinations, we had chances to find a number of bad and good performance measurements over the iteration of 90 runs. But it is impossible to find all the gene combinations through the random process.

After the second generation, the system tries to measure other poorer performance cases with the help of the GA. Before the GA process begins, all genes are sorted form bad performance levels to good performance levels based on the GA objective function that forces the system for getting worse performance results to measure the limit of the system.

In the Figure 8.5, Figure 8.6, Figure 8.7, and Figure 8.8 are shown the some performance results for two different generations. With the enforcements of GA objective function, the system treats to have higher error rates under the high loads between 450 and 600 high payload sizes. But after the 45 runs, system starts to use low load size between 45 and 120 low payload sizes by the effect of random process, and these low rate loads cause low error rates.

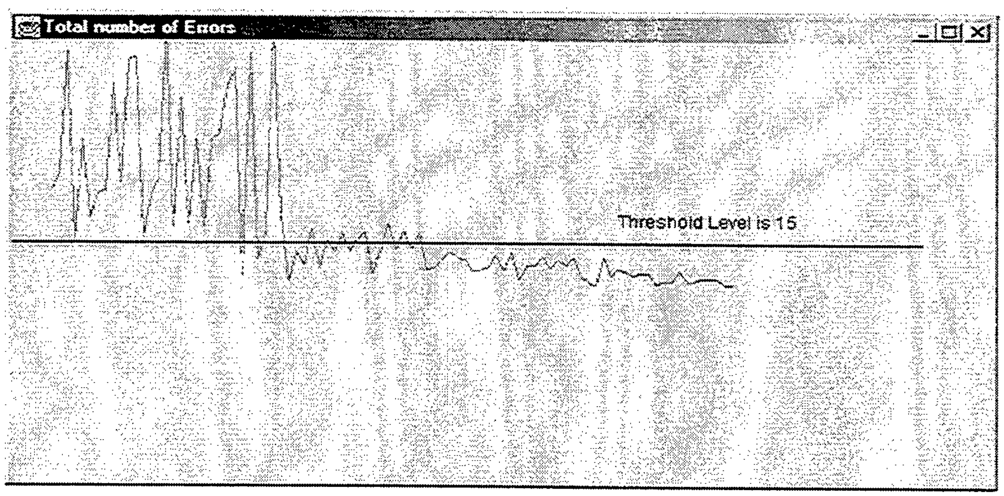

Figure 8.5. System total error rates for 90 experimental conditions

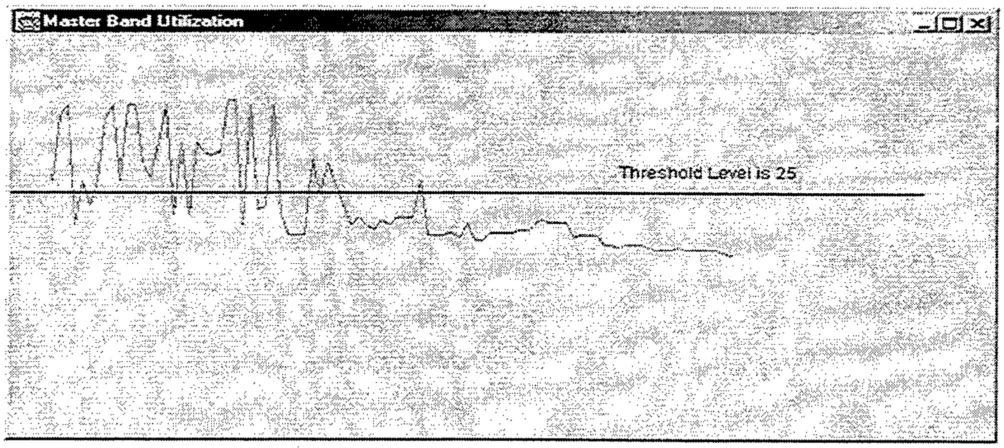

Figure 8.6. Master band utilization for 90 experimental conditions

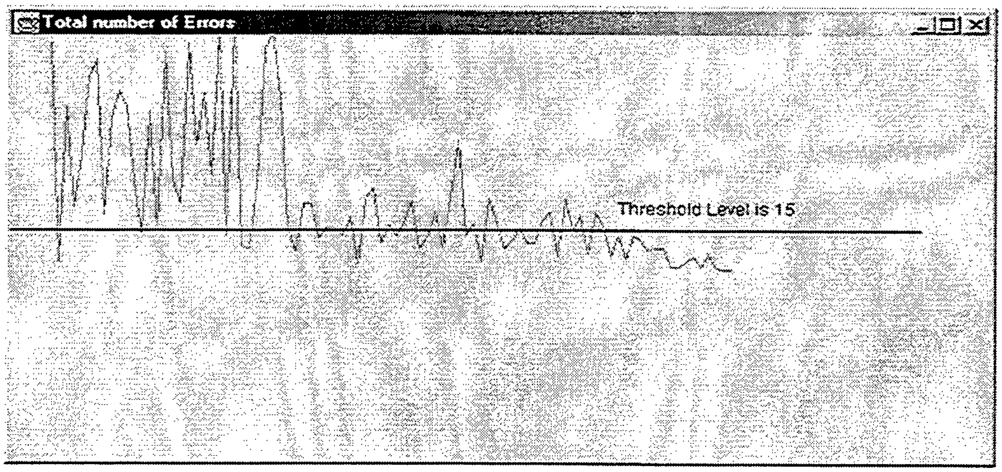

Figure 8.7. System total error rates for 90 experimental conditions

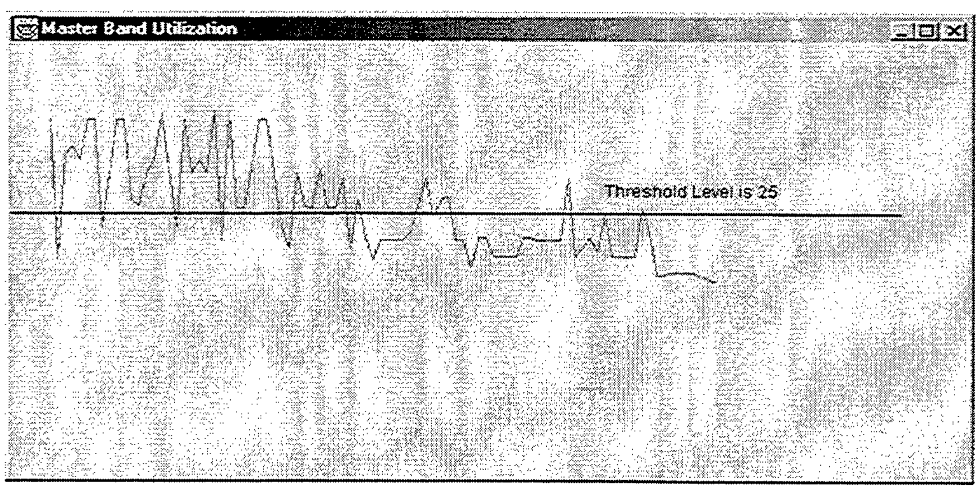

Figure 8.8. Master band utilization for 90 experimental conditions

In conclusion, this experiment shows that the Demand layer was able to find demand conditions that produced poor performance in the Infrastructure Layer. However, since we ran the system for 20 generations, we should run the simulation between 50 and 500 generation for getting better results by definition of the GA.

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IX. CONCLUSION AND FUTURE WORK

A. CONCLUSIONS

This thesis presented the design, development, implementation, and analysis of wireless world simulation on a standalone computer. The wireless world simulation provides a realistic, believable bottom-up simulation approach for modeling of Bluetooth Technology (BT). The assembled code provides a unique and broad approach to modeling the BT system using the object oriented Java programming language that was used as a tool for developing an application program in the environment of Borland Jbuilder3 university edition editor environment. Moreover, the wireless world includes a Windows^{TM} compliant graphical user interface as well as data storage and information retrieval capabilities.

MAS simulation provides a unique way to explore the system during the design phase of a system. It is hoped that this system, as an initial effort, will be the motivator for other efforts to develop new systems and benefit other designs and as an inspiration to develop additional dedicated, focused systems.

B. FUTURE WORKS

This section focuses on some possible future enhancements and modifications to the wireless world model presented in this thesis. Many of these enhancements would

add to the realistic representation of the Bluetooth System, and provide designers better and robust simulation characteristics.

- More work is needed to improve the communication environment.

- More BT system specification can be add into the infrastructure layer.

- More realistic approaches are required to improve the effects of the interference systems.

- The model can be expanded and redesigned adding the specifications of the entire IEEE 802.11b system into the simulation environment, and analyzed its performances and interference effects of both technologies operating together.

- A detailed performance analysis can be required for a number of different experimental configurations and settings.

- Different kinds of GA approaches can be applied the system to get the better results.

- More realistic assumption is required for the objective (fitness) function of GA to improve the system capabilities.

- Additional new interference system could be added to the potential interference list.

- More work is need to improve the usability and human computer interaction of the wireless world model.

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